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CONTROL OF RATS AND MICE

VOLUME 3

HOUSE MICE

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ABBREVIATIONS

A.R.C.	Agricultural Research Council
A.L.D.	Average Lethal Dose
Antu	α-naphthylthiourea
B.S.	British Standard
B.S.I.	British Standards Institute
L.A.	Local Authority
L.D.	Lethal Dose
M.A.F.	Ministry of Agriculture and Fisheries
M.O.F.	Ministry of Food
M.O.H.	Medical Officer of Health
M.O.S.	Ministry of Supply
P_3	Protected Poison Point
P.L.H.A.	Port of London Health Authority
R.C.T.	Rat Control Test
S.A.L.A.M.	Société Anonyme Levant-Africaine Méditerranée
W.A.E.C.	War Agricultural Executive Committee

INTRODUCTION

THE work of the Bureau of Animal Population during 1939–45 was mainly concentrated on the biology and control of the brown rat. It was not until half-way through the war that any systematic and full-time research upon house mice was planned. Nevertheless, the possibility of such work was kept in view right from the beginning, and the formulation of the problem together with the discovery that methods developed for rats could not be merely adapted to mice were the result of preliminary work done by the Director, Mr. Charles Elton, between June 1940 and May 1942. After this H. N. Southern took over the house mouse problem as his main work. Miss E. M. O. Laurie assisted officially from the autumn of 1943, though she had helped for some months previously while she was working for a B.Sc. degree on the reproduction of house mice in various habitats. Finally, from August 1943 Dr. J. Rzóska also gave most of his time to house mice in collaboration with Southern and Miss Laurie.

The purpose of this introduction is, therefore, to outline the main contributions made by each member of this research team to the body of information contained in this volume. It is simplest to sketch the development of the research chronologically.

As early as April 1940 Mr. H. R. Hewer made a survey of urban (mainly shop) premises in Oxford for the purpose of estimating rat infestations and he included instances of serious damage by house mice. Partly as a result of this Elton started work in several grocers' shops and stores from June 1940 and continued intermittently until September 1941. Elton established beyond doubt the seriousness of the losses due to house mice in such places. Experiments were directed mainly to making rough estimates of populations, to testing the effect of trapping upon them, to studying the reactions of mice to bait boxes and plain baits, and to attempting control with permanent poison baits.

Since the last project failed, and since the technique of surplus prebaiting by then had been developed for rats by D. H. Chitty, from April 1941 the emphasis of the research veered to studying the daily consumption of surplus plain bait over a period and the effect of temporary inclusion of poisons. More intensive work was forwarded by using certain cellars and sheds in the Oxford Museum area where house mice could be liberated and studied on these lines.

Finally, between November 1941 and February 1942, Elton turned his attention to the difficult problem presented by bulk food stores and made preliminary observations at a M.O.F. flour store on the numbers of mice and their reactions when he provided plain bait for them.

In May 1942, when Southern started full-time work upon house mice, he carried on the 'field' tests of baiting and poisoning sequences in Oxford

shops, and at the same time initiated a series of laboratory projects to break up the 'field' problem into simpler components for separate study.

In the first place he started a series of group free-feeding tests upon house mice to gather preliminary information on the mode of action and acceptability of a wide variety of poisons at different concentrations, and on the amount of poison bait relative to prebait which mice would eat in a successful field trial. Throughout the rest of the work all poisons, as they came to the Bureau's notice, underwent a quick, exploratory test in this way.

Again, since the amount of plain bait eaten during field trials varied greatly and the results of poisoning were poor, two complementary lines of investigation were pursued: (1) the tracing of the mean daily range of house mice by means of dyes mixed with the food of an experimental, free-living population, (2) the determination of the order of preference between different plain baits by choice tests on another free-living population.

Southern pursued these investigations throughout the autumn and winter of 1942–3. The characteristic distribution of mice resulting from the smallness of each animal's range enabled him to classify infestations according to the distribution of cover and food, and this classification was important from the point of view of control. 'Easy' infestations were those in which shelter and food were separated so that baiting could intercept the mice travelling from one to the other; 'difficult' infestations were those in which cover and food were co-extensive, the worst examples being bulk food stores and corn-ricks. Here baiting could only be really successful if the bait was extremely desirable to the mice. In between these extremes fell the general run of urban infestations, where cover and food were distributed piecemeal and intermingled in various degrees.

Since the successful baiting of mice in these environments became a question of taking the bait to the mice (owing to their small ranges and lack of any notable food preferences) instead of drawing the mice to the bait, as can be done with rats, there was gradually built up a technique of prebaiting, after a preliminary choice test, with many small baits widely disseminated, so that the routes between food and cover stood out and the mice could be intercepted more successfully.

A further problem was how to ensure, even when all mice had been brought into contact with the plain prebait, that they should eat a lethal dose of poison when this was laid. Again what was the behaviour of any survivors of a poison campaign, i.e. were they thenceforward shy of the poison and/or the bait base?

Accordingly in February 1943 Southern began a series of laboratory experiments on feeding behaviour which lasted until February 1946. In these the normal feeding rhythm and the approach to poison bait were analysed by means of an electrical recording apparatus, which registered the number and frequency of visits to food trays.

From 1944 these experiments were linked with laboratory feeding tests by Rzóska, in which various doses of different poisons were given to domestic and wild mice and the resulting behaviour to plain bait and subsequent poison baits observed.

These two parallel lines of work established that shyness towards poison baits did occur in house mice, but did not extend to the bait base in which the poison was mixed. They also showed that the sporadic feeding habits of mice made it very difficult to ensure that all mice visiting the prebait ate a lethal dose of poison bait.

During the whole of this period field trials with progressive modifications were carried out in Oxford by Southern, Rzóska, and Miss Laurie until in all but the most difficult environments a routine poisoning system was evolved, which would kill 80–90% of the population.

While this intensive analysis of feeding behaviour was going on a determined attempt was made to tackle the really difficult environments such as corn-ricks and bulk food stores, where cover and food were one, even if this meant resorting to hit-and-miss methods.

From March to November 1943 Southern and Miss Laurie collaborated in an attempt to kill house mice in corn-ricks by large-scale baiting with moist sausage-rusk and zinc phosphide. The results, no doubt because of the dryness of the environment, were successful beyond expectation, and kills (verified at threshing) of between 60 and 90% were easily attainable. It proved impracticable, however, to recommend these methods because the small residues of poison bait exceeded the safety margin.

An attempt was made to circumvent this by using extract of red squill powder which had proved very toxic to house mice in laboratory tests, but in the field this poison proved useless. For the time work on corn-ricks was abandoned though between August 1943 and June 1944 Southern and Miss Laurie studied by means of break-back trapping the distribution of house mice in the fields around the ricks. This showed the presence throughout the year of a substantial number of mice living in the fields, so that even complete killing of mice in ricks before or after threshing would not prevent the next season's corn from being infested.

The other difficult environment—the bulk food store—was studied by Southern and Rzóska with help from Miss Laurie. In the summer of 1943 experiments began at a M.O.F. buffer depot on the outskirts of Oxford and these continued until March 1944. This depot contained sacked oats and white flour, which are peculiarly liable to damage by mice. Throughout a long series of tests no reasonably satisfactory results were obtained, although prebaiting was very successful.

Accordingly, at the suggestion of Rzóska, attention was turned to fumigation for killing house mice in these difficult, 'homogeneous' environments. Carbon dioxide was chosen since it could easily be obtained in solid form and was not dangerous to handle. The summer of 1944 was spent by

Southern and Rzóska in establishing the toxicity curve of house mice in carbon dioxide-air mixtures upon adequate laboratory data and in making preparations for field tests in a specially built stack of oat sacks which could be enveloped in a gas-proof cover. These field tests were carried out in the autumn of 1944 and were completely successful.

In consequence the use of carbon dioxide under a cover was extended to corn-ricks and a series of tests was made in the spring of 1945 by Miss Laurie and A. D. Middleton in Northumberland. The small round ricks characteristic of this area proved ideal for experimental purposes and again complete kills were obtained, provided the requisite concentration was reached.

Finally, during the summer of 1945 an attempt was made to extend this method to large corn-ricks. This work was done mainly by Middleton and Miss Laurie with assistance from Southern in the later stages. It proved possible to fumigate large ricks in this way, but the apparatus needed was becoming very unwieldy and it seemed that the project would hardly be economical without further research.

At this point the active part of the research was discontinued, but a further year was occupied in completing reports of the work for the Agricultural Research Council. Then in 1947 Southern began the task of writing up the results in their present form. Most of the chapters, as they stand, have been completely recast from the original reports and many are put together from data which never appeared in reports. Fortunately both Rzóska and Miss Laurie remained available for consultation until the volume was completed.

The second section of Chapter 15 (on gassing corn-ricks) was written by Middleton and Miss Laurie. Chapter 10 is based largely on Rzóska's report of his free-feeding tests. Otherwise the responsibility for the writing rests with Southern. Many of the original data are given, but there are naturally many records of experiments and field observations whose inclusion would be bulky and unnecessary. These are deposited in the Bureau of Animal Population.

* * *

This research was carried out during the war under the auspices of the Agricultural Research Council. A fuller account of its history may be read in the first chapter of Volume 1. The publication of the results has been eventually achieved through the sympathetic attitude of the Delegates of the Clarendon Press and a generous gift by an anonymous donor.

I

A BRIEF NOTE ON THE WORLD DISTRIBUTION AND ECOLOGY OF *MUS MUSCULUS* L.

THE genus *Mus* is most closely related to *Rattus*; indeed their separation into two genera is based on fairly slight characters in the skull, which show occasional overlap (Ellerman, 1941).

The systematics of the genus are still rather confused owing to the amount of involuntary movement of some forms about the world and the plasticity of some of the characters used. Ellerman divides the genus into five species groups, of which those other than *musculus* are Oriental or Ethiopian and have travelled comparatively little. The original distribution of *musculus* was certainly Palaearctic, but now extends to the Oriental, Australasian, and Ethiopian regions and also to the New World.

Schwarz and Schwarz (1943) suggest that the house mouse spread from an original white-bellied short-tailed stock in Central Asia (so-called *wagneri*) along various highways each showing progressive changes to greyer bellies and longer tails in step with increasing commensalism with man. This is an interesting speculation. These characters, however, are so plastic that it is not possible to accept their analysis as any more than a speculation; the details are discussed more fully in Southern and Laurie (1946). Kuznetzov (1944) accepts the position that it is not possible to divide house mice of the U.S.S.R. into species or even into satisfactory major subspecific groups, so he brings them all under *musculus*. He notes that in true wild mice in various parts of Russia the colour of the belly varies from white to dirty grey and the tail length from 75 to 90% of the body length. There is, however, this much to be said for the Schwarzs' hypothesis; some of the approximate subspecies groupings (e.g. *spicilegus* and *bactrianus*) show more constant differences than others, and it is just in these presumably authochthonous Asiatic groups that lighter bellies and shorter tails occur.

The information given by Russian authors (e.g. Fenyuk, 1941) shows that *Mus musculus* is an animal of dry steppes, living largely on weed seeds, so it is not remarkable that it has followed agriculture all over the world. An interesting comment is found in Baker (1946), who says that the commensal stock living wild in the Pacific island of Guam prefers dry slopes to the wetter flatlands. In most of the U.S.S.R. the mouse is an animal of the fields, but takes to living in buildings in the northern part of its range. This adaptability enables it to tolerate a wide range of temperature and of climatic conditions generally.

In most of the areas, where *M. musculus* lives as a commensal with man

the situation is reversed: it is mainly a house dweller, but may live out in the fields either for part of the year, or for the whole of the year in small numbers. Southern and Laurie (1946) showed that in England there is a permanent, thinly spread population living and breeding in the fields, while denser populations are built up seasonally in corn-ricks. Occasionally, however, commensal forms of house mice take to living in the fields again, as in Australia and some other parts of the world.

This gradual transition from free-living to commensal habits, which accompanies the slight morphological changes mentioned above, is emphasized in certain areas such as the Himalayas (Schwarz and Schwarz, loc. cit.) where commensal and free-living stocks may occupy the same area but remain relatively isolated from each other. The recent study by Evans (1949) in America on populations of house mice living within buildings and in the country surrounding them is interesting. He verified by marking that there was little traffic between the indoor and the outdoor populations and that demographically they were behaving very differently.

Finally, mention should be made of the distribution of house mouse 'plagues'. Russian authors (e.g. Kalabukhov and Raevskii, 1933; Kalabukhov, 1937) describe the vole-like peaks of abundance which occur in field-living populations of the steppes and tentatively connect them with changes in the crops of weed seed. In some parts of the world free-living commensal stocks also do this. In Australia densities of quite extraordinary magnitude are recorded at intervals, and the same thing occurs in the United States of America. Elton (1942) has given a summary of some of these outbreaks.

Such plagues constitute a major economic loss to man and focus attention on the house mouse as a serious pest. It is probable, however, that the continual drain upon economic resources on a less spectacular scale, which results from the world-wide commensal stocks, is in sum a far more serious matter. The house mouse certainly merits as much attention as any other vertebrate 'pest'.

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2

THE HOUSE MOUSE AND ITS ENVIRONMENT

1. THE MOUSE'S HABITAT

THE last chapter indicated what was the natural habitat of the house mouse and how it has adapted itself to living with man. In this chapter will be considered the relative importance of the various factors in these new environments in maintaining house mouse populations. This is ultimately the same thing as saying the amount of loss to man's economy, since the species has so completely assumed the role of a commensal. These environmental factors may be discussed preliminarily under three headings: (*a*) cover and food supply, (*b*) climate and food requirements, and (*c*) disturbance and nocturnal habits.

(*a*) Cover and food supply

Under natural conditions house mouse populations are possibly controlled by predators. At certain times, which may recur in a cyclical sequence, and in certain parts of the world, notably in large grain-producing areas, the primary method of control breaks down and increases amounting to plagues occur. Whether, since such outbreaks occur mostly in farming country, these plagues are ultimately man-made is not certain (data on this point are given in Elton (1942) and Southern and Laurie (1946)). It seems likely, but so many small rodents exhibit these great fluctuations, that they may be natural in house mice as well. However, it will be safe to say that most of the time predation is the main agent of control. In a wild state the cover used by house mice is either thick vegetation or burrows and in either case they may be preyed on while they are out feeding. In the artificial habitats provided by man not only may their cover embrace all their activities including feeding, but even where they are exposed to the risk of being killed when moving about their habitat, these risks must be far lower and more intermittent than in the wild.

The result is that house mouse populations follow a series of minor fluctuations, since predation (man's activity with traps or poisons) is only exerted when the mice increase sufficiently to be more than a mild annoyance. Short of complete extermination the best method of control would be some arrangement which simulated predators in exerting on the population a pressure which was continuous and self-adjusting to the density of the mice. Permanent poison baits are theoretically the ideal way of achieving this, but, as will be seen later, there are great practical difficulties in the way of using these. The use of a domestic predator, like the cat, is only

a palliative, since buildings contain such a network of refuges. Campaigns must continue, therefore, to be periodic.

In such campaigns, which may well be costly in labour and materials, it is essential to achieve the greatest possible efficiency, and this cannot be done without a knowledge of the habits and movements of house mice.

The mouse is most vulnerable to predation, whether this takes the form of claws or poison, in its movements between cover and food, and so the complex variations in the relations between these two necessities must be studied first. The use of the word 'cover' will be restricted in these discussions to mean anything that gives refuge to mice from the would-be controller and in which, so long as they remain, they are safe. Obviously commercial premises, e.g. a grocer's shop, when locked up for the night constitute a solid block of 'cover' in which mice can move about safely, but to avoid confusion the word will not be used in this sense.

The relation between cover and food supply may vary between two extremes. On the one hand, there is the type of habitat in which the two are widely separated. This is often due to a shortage of food because the mice must increase their range to find enough (infestations in factories and buildings where the food consists of scraps imported daily by a careless staff come in this list). These conditions arise when food is removed: in food stores which have been emptied the mice in addition to having much of their cover pulled down have to hunt for their food harder than they did before.

In circumstances such as these house mice are usually not difficult to poison, even without the preliminary use of plain bait (see Ch. 8). Even where food is abundant it is usually possible to deflect the mice to baits by placing these between their cover and their food supply.

At the other extreme are the infestations where cover and food coincide and the mice need never come into the open at all. The main examples of such conditions are corn-ricks, food stores where sacked grain, flour, &c. are piled up in large stacks, and cold stores where meat is kept. These places together probably constitute the greatest source of economic loss in any country because of the size of the infestations and the loss and spoiling of food they entail. They certainly present the most difficult problem to research upon control. Results have in fact shown that the most satisfactory way of dealing with infestations such as these is by gassing under a gas-proof cover (see Ch. 14) but, where this is impracticable, a moderate success can be achieved by other methods. For this purpose, therefore, we must know something about how far a mouse will move about in the stacks, and what proportion of the population visits the margins.

Between these two extremes there exists every gradation of intermediate conditions exhibited in urban shop and house infestations. Generally speaking, these are not so difficult to treat as food stores and corn-ricks,

but the unreliability of results in poison campaigns has been the most baffling aspect of the problems. Most of the energies of the Bureau's mouse research have been absorbed in answering the question why results are so variable, and little time has been left for applying the knowledge which we have now obtained. It is obvious that the extreme complication of the environment, in which cover and food are divided into little bits and mixed up with one another, will make interception and poisoning difficult.

The course of research upon house mice has fallen into three phases, which follow each other logically. First of all we must make sure that each mouse in the population risks being poisoned, i.e. there must be one bait at least in every mouse's range. The second task is to ensure that every mouse pays attention to the bait, which must therefore be either attractive or accustomed: and thirdly, each mouse must eat sufficient poison bait to be killed. The first problem is basic to the other two, since if part of the population escapes the risk of being killed, all other refinements of technique will be useless.

The assumption that there is such a thing as a mouse's range, the boundaries of which it transgresses rarely, is substantiated by experiment and observation in this chapter. Thus, there is a difference in behaviour between the house mouse and the brown rat, since the latter ranges more widely and so can be baited with fewer points. In addition, rats can be drawn to bait more easily than mice, so that with mice it is more a question of taking the baits *to them* than of bringing them to the baits.

If a mouse's range is large (either because food is widely separated from cover, or is scarce) it is more vulnerable to poison baiting, just as to other forms of predation. We may, therefore, expect that under optimum conditions the range of a house mouse will be small, and that its 'protective system' (Elton, 1939) will be adapted to this end. This is considered in the second section of this chapter.

(*b*) Climate and food requirements

The effect of climate in the wide sense upon the geographical range of the house mouse has been noted in Chapter 1. Here we are mainly concerned with the more particular relations between individual physical factors and the mouse's behaviour.

Consider first *temperature*. Small mammals are known to be less efficient than large ones in resisting low temperatures and under severe conditions, e.g. in Arctic regions, they can only survive by seeking cover which also acts as insulation. Thus endemic species are protected by snow cover and/or burrows, while immigrants such as the house mouse remain closely associated with houses and other buildings. Autumn and early winter movements into ricks and houses are well known and documented in some parts of the world (see Southern and Laurie, 1946), and the same thing certainly occurs in this country. Southern and Laurie also show that the numbers

of field-living mice decline in the winter. It is probable that many bad infestations establish themselves at this time of year.

Cold stores for preserving meat in bulk have enabled many observations to be made upon the effect of cold on the behaviour of mice. The main facts about these conditions as they affect reproduction are described in Laurie (1946). The other points of interest are that the mice were able to maintain themselves in good health at about 15° F. if one can judge from their weights which were well above the average for mice in other habitats. Body heat was conserved by living in the best insulated parts of the stores, either in the cork-lined walls or in the middle of carcases, where nests of shredded sacking were made.

Probably the type of food plays a part in maintaining health under such conditions. Usually the parts of the carcases preferred were the regions round the kidneys, presumably including the adrenals, so that plenty of protein and vitamins were available. In addition the supply of food is almost unlimited in quantity and constantly renewed, and frozen atmospheric moisture would ensure plenty of water quite apart from that contained in the flesh.

For resistance to cold the quantity of food available is as important as the quality, since an increase over the normal consumption is necessary to maintain body heat. An experiment which was carried out at Oxford gives some information about this. Eleven mice were placed in Topley cages in an unheated shed and supplied with sausage-rusk mash. After the experiment began, a period of very cold weather with temperatures around freezing-point occurred, but it was not thought worth breaking off the experiment. The mean daily consumption (dry weight) of sausage-rusk under normal temperatures has been calculated from a long series of observations (see Ch. 3) and the figure is 3·62 g.: under the cold conditions of this experiment the mean consumption was 4·52 g., an increase of nearly a third.

At the other extreme house mice need protection against excessive heat. Toraude (1933) has shown that in still air a mouse will die within 5 minutes if exposed to direct sunlight. It is not stated what kind of mice he used; if they were albinos, it is probable that wild mice would have a greater tolerance than this. Even so, it is clear that, whether death was due to heat stroke (mice like other mammals can only get rid of body heat by losing water from the lungs) or to insolation, cover on hot days is necessary to mice.

At high temperatures the daily consumption of food is reduced (see figures given in Ch. 3), but thirst necessarily increases. We must emphasize here the difference between a diet and water supply upon which house mice can survive and one upon which they thrive. Many populations are living at conditions considerably below the optimum, but manage to survive and even increase because of the reduced stringency of some mortality factors. There is no doubt that mice can exist with extremely little

water, especially if their cover gives them protection from heat. McClintock (1859) mentions an instance in which a barrel of biscuits, sealed in Aberdeen, and opened in the Canadian Arctic over 14 months afterwards, was found to contain a live mouse. Finlayson (1939) kept wild mice in captivity for over 2 years without supplying them with water, and at first the Bureau's stock was kept similarly. The mice stayed in apparently good health, but since they did not increase in weight satisfactorily, water and some other additions to their diet were given.

Bing and Mendel (1931) in a series of experiments with tame mice showed that water was a necessary part of the diet and found that the ratio of water drunk to solid was about 1·3 : 1. A series of observations made at Oxford with wild mice however gave a figure of 0·5 : 1 (mean consumption of water by eleven mice for 11 days was 1·50 ml.; of food 3·05 g.) under normal conditions of temperature and with rolled oats as food. In most habitats therefore mice will not suffer greatly from lack of water, so dry baits are not at any disadvantage compared with moist ones. However, in places like corn-ricks and food stores, especially in hot weather, the lack of water does seem serious, and moist baits are preferred to dry ones. An experiment upon the choice of house mice between wet and dry baits in relation to temperature is described in Chapter 7, and it was clear from this that whenever the temperature rose the mice changed from the dry to the wet food.

No detailed experiments were carried out on the type of diet which is best for house mice, though certain data are presented in Chapter 7. These tests were rather of the hit-or-miss variety, such as is necessary for quick results in wartime, but they show that in certain conditions the addition of oil to a cereal diet is preferred by the mice. An extended investigation into the effect of different diets on the condition (growth) and reproduction of tame mice was carried out by Watson (1937). The diets used fell roughly into three categories: a plain cereal diet (whole oats); the same with the addition of salt mixtures and vitamins; and thirdly a diet in which about half of the cereal was replaced by milk powder. Equal parts of milk and water were given to drink throughout. On the first diet the mice maintained themselves fairly well, but the incidence of litter-eating was high and the growth of surviving young poor: on the second diet the incidence of litter-eating declined markedly, but the growth of the young was still poor: the third diet gave the best results of all.

These results help us to assess the effect on wild mice of the different habitats in which they live. They suggest that in spite of the apparent optimum conditions prevailing in a corn-rick, the diet will not be good for raising young, even when we allow for the fact that tame mice will undoubtedly be less hardy than wild ones. Observations by Elton in a M.O.F. buffer depot, in which the only available food was white flour, showed that there were remarkably few young in the population (a nest was

found in which the young had had their heads bitten off) and that many of the adult mice suffered from bare patches on the skin, all consistent with a deficiency of vitamin B_2. Similarly, when a badly damaged store of bagged oats was removed from another M.O.F. buffer depot, although some hundreds of mice were killed, only one nest with live young was found. Wheat seems to be the least unsatisfactory of our three main cereals as an unsupplemented diet. Populations of mice in corn-ricks (Southern and Laurie, 1946) reach excessive densities only in the case of wheat. Figures for barley and oat stacks are very variable, but on the whole much lower (see results of national corn-rick inquiry, Vol. 2, Ch. 11). There may be other factors responsible for this besides the dietetic qualities of the different grains (for instance it seems probable that mice avoid barley-ricks because of the spiky awns), but wheat has a slightly higher content of protein and vitamin A than the other two.

Even so it is noticeable that in any rick which has reached a certain age or density the mice cease to increase and the population then remains steady.

We lose so much grain every year because corn-ricks give mice protection from enemies and climate, and they increase in spite of the poor diet. In other habitats, such as urban shops and stores, the diet is undoubtedly more mixed (see Ch. 3) and the restraints on the population increase are disturbance and (even inefficient) control campaigns.

(*c*) Disturbance and nocturnal habit

The feeding rhythm of the house mouse and its adjustment to day and night are discussed fully in Chapter 6. There is a basic 24-hour rhythm with most of the feeding taking place during dark: there is, however, considerable plasticity, and day-time feeding is not uncommon in certain groups and individuals. This means that in habitats, where mice are undisturbed for long periods, e.g. in food stores and in many smaller storehouses, such as those which are attached to grocers' shops and are infrequently visited, they have almost unlimited time for searching and feeding. In shops themselves, where people are moving about during the day, the mice are active only at night, and must keep to their basic feeding rhythm. These variations between habitats are important for determining the time to place baits in control campaigns.

Since the house mouse is primarily adapted for searching and feeding at night, it follows that in places where cover is separated from food they rely very much on knowing thoroughly the spatial relationships of their local environment (this is discussed in the next section). This seems the only way in which to explain the quite remarkable effect on the mice of a thorough disturbance of their environment.

Domestic house mice may take as much as 3 weeks to settle down in a new series of cages and start breeding. Wild mice are no doubt less sensitive

than this, but Elton discovered during a survey of large grocers' stores in Oxford that before the Second World War, when there was a continual turnover of goods, mice had little chance to get established. Periodic destruction or rearrangement of their environment is one of the best ways of controlling mice in places where they are not repressed by food shortage.

All these considerations of climate, diet, and disturbance give a background for judging how serious any infestation may become and for sketching the main lines upon which to plan control measures.

2. THE MOUSE'S SENSES

The relative importance of the senses of house mice indicates the type of behaviour to be expected. Much of the information that follows is taken from Waugh (1910).

(*a*) Sight

The eye of the house mouse is not constructed for clear perception of form: on the other hand, it is very sensitive to variation in light intensities and consequently to changes of pattern in the whole visual field. Movements are perceived very quickly and either elicit 'attentive' behaviour, in which the mouse waits on the alert for further sensory information, or immediate flight. If no further movement occurs in the environment, the mouse resumes its normal occupations. Judging from the size of the eye, there is no particular adaptation to nocturnal life, but there is a general tendency to be more active at night, and this is probably controlled partly through light intensity (compare results given in Ch. 6).

(*b*) Hearing

Sounds, especially of higher frequencies, are quickly perceived by mice, and are evidently most important in providing information about danger. Even the slightest squeak, if it is high pitched, will arrest attention and a loud noise produces instant flight.

(*c*) Taste and smell

Both these factors play an undoubted part in the mouse's defences against a poison campaign. Taste certainly and smell probably will reveal to a mouse whether it has previously had an unpleasant experience with the bait offered. This subject is discussed by Miss Shorten for rats in chapter 5 of volume 1 and more shortly for mice in chapters 8 and 9 of this volume. There is no doubt that smell is used to a large extent in locating food.

(*d*) Kinaesthetic sense

This is very important to mice, especially in governing flight reactions after sight and hearing have revealed the presence of danger. Their reliance on this sense may explain the smallness of the daily range. A mouse's journeyings, especially when carried out quickly, are governed by the

constant practice of sequences of muscular movements. This is only to be expected when so much of their activity takes place in the dark. Therefore the home range of each mouse is known to it in terms of these muscular habits of which the right one is activated automatically when danger threatens. For the first hour after a mouse has been placed in a new cage it explores it intensively, moving back and forth continually all over the cage. Table 1 shows the activity of three mice, measured by an activity recorder from the time (10.45 hrs.) when they were first placed in their cages.

TABLE 1. *Hourly activity of wild mice after introduction into new cage*

Hour:	*10–*	*11–*	*12–*	*13–*	*14–*	*15–*	*16–*	*17–*	*18–*	*19–*	*20–*	*21–*	*22–*	*23–*	*24–*	*1–*	*2–*
Mouse A .	3	8	3	4	4	1	0	0	0	0	0	0	0	0	1	1	0
,, B . .	2	5	1	0	1	0	0	0	0	0	0	1	1	1	0	0	1
,, C . .	0	4	4	0	2	0	1	0	0	0	0	0	1	1	0	0	0

The activity index is explained in Chapter 6.

The results of this exploratory behaviour are shown well in the change of reaction before and after it has taken place. If we take off the top of a cage into which a mouse has just been placed it merely makes a wild leap: after an hour or so, however, it darts straight into its cover box.

Such behaviour is not confined to the first moments in a new environment. It is exhibited constantly by mice in a less intense way, especially during the period of nocturnal activity, and so presumably they gain information of any change that has taken place. This may be why mice avoid new objects less than rats (see Vol. 2, Ch. 5). A change is for them something to be investigated and learned, so that the necessary adjustments in kinaesthetic memory may be made.

(*e*) Touch

This sense seems important to mice in taking cover. Any narrow retreat into which they can squeeze, even though its sides may be of glass or wire netting, leaving the mouse fully exposed to view, will satisfy them.

These facts show how a mouse benefits by having a small range. A large range is possible and obligatory at times, e.g. when food is short, but the mouse becomes far more vulnerable to all kinds of attack, including poison baiting.

3. EXPERIMENTAL EVIDENCE ON THE NORMAL DAILY RANGE OF HOUSE MICE

For convenience we may consider the normal daily range as the mean size of territory which a mouse may cover, shared or unshared with other mice, during 24 hours with plentiful food and no undue separation between it and cover.

The experiments designed to investigate this problem were carried out in a mouse-proofed cellar at Oxford in which caged stocks of voles were

kept. This measured 25×11 ft. and contained plenty of cover (benches, old cages stacked in piles, various old boxes and junk, and in addition six small cover boxes placed on an 8-in. ledge which ran around the cellar at head level); the temperature was fairly constant (*c.* 18° C.) and relative humidity was generally about 75%. A constant day length of 13 hours was maintained by an automatic time switch for the lighting system, which consisted of two 75-watt bulbs one at either end of the cellar.

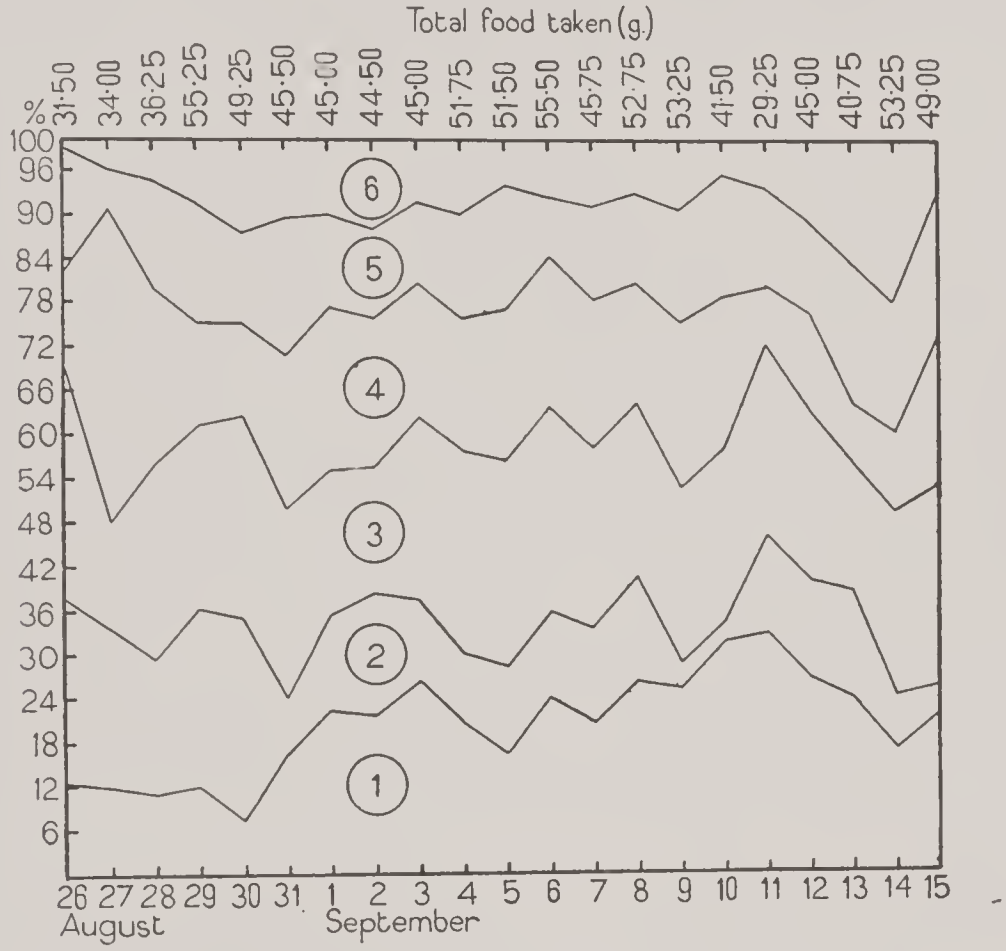

FIG. 1. Distribution of food consumption between six feeding points (in amounts per cent. of each night's total).

A preliminary experiment was run for 3 weeks, during which various methods of colouring the food so as to produce visibly stained faecal pellets were tried. Eight mice were released and six jars containing dry rolled oats were distributed at random round the cellar. These were not moved during the experiment and the amount eaten from each was weighed every morning.

Some results of interest were shown by the distribution of feeding from day to day and these were confirmed by the subsequent, main experiment.

If we suppose that each of the mice had been moving all over the cellar at random each night and taking food impartially from all the points, the total consumption for the night should have been divided equally between the six points, and this equal distribution should have been maintained

throughout the experiment at a constant level. Fig. 1 would have parallel lines at equal intervals.

On the other hand, if the mice had such a short area of search that they fed each night from the food point nearest to their cover, then, although the amount of food taken from each point might vary, it would vary constantly (providing the mice were not changing their ranges, which seems unlikely) and so Fig. 1 would have parallel lines at unequal intervals.

In fact, neither of these extremes occurred. The amount of food taken from each point varied within wide limits, and these variations were mostly short-term ones with an amplitude of a few days only. Point 1, and to a less degree points 2 and 6, only showed a gradual increase or decrease throughout the experiment.

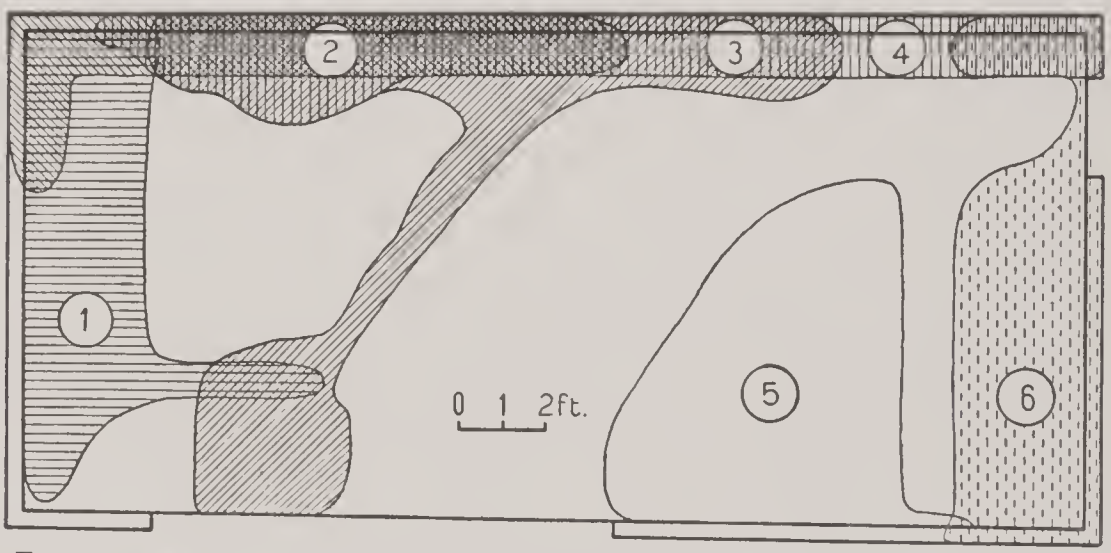

FIG. 2. Ranges of house mice patronizing each feeding point (traced by colouring the food successively at each point).

The mice, therefore, confined their feeding to a few points only, probably with some variation on different nights. It is unlikely that such a graph would result from all the ranges being coincident over the whole of the cellar, or from none of them being coincident.

For the main experiment twelve wild house mice caught from a rick a few days previously were released in the cellar. They were a normal sample of a wild population as far as weights and sex ratio went:

7 males . . .	(8–16·5 g.)
5 females . . .	(10–17 g.)

In this experiment stains were mixed with the food. For one night at each of the food points in turn 0·5% water soluble eosin and 10% gypsum were included and the distribution of coloured faeces mapped. This mixture proved excellent for the purpose, because gypsum alone did not make the pellets light enough to be at once distinguishable but provided a lightening base in which the red stain showed up.

The main results are shown in Fig. 2. It is difficult to show the ranges

on a plan when they were really extended in three dimensions (owing to benches, ledges, &c.) but the salient features of the distribution are clear enough. Much of the open space left on the figure is empty floor, and one would not expect to find many pellets here, because presumably mice move across such open spaces quickly. They have probably therefore covered more of the actual space than is shown.

Furthermore the figure shows only ranges for 24 hours and it is clear that some variation may be expected and that total ranges will be somewhat larger than daily ones, which are being considered here.

The figures for this experiment are as follows:

Area (sq. ft.) covered by mice feeding at point				1	= 66 (including 4 sq. ft. of range 4)
,,	,,	,,	,,	2	= 30 (all in other ranges)
,,	,,	,,	,,	3	= 50
,,	,,	,,	,,	4	= 48 (including 24 sq. ft. of range 3)
,,	,,	,,	,,	5	= 49
,,	,,	,,	,,	6	= 42 (including 2 sq. ft. of range 4 and 4 sq. ft. of range 5)
Total area searched					285 sq. ft.
Total minus overlaps					221 sq. ft.

The floor space of the cellar was 264 sq. ft.: that of the benches and shelves 142 sq. ft., making a total of 406 sq. ft. Thus only about half of the total area was searched by the mice. Some of the empty space may in fact have been traversed but it is clear that searching is not carried out with equal intensity over such a habitat as this, and this may be due to the restricted nature of the individual ranges.

The average area at all levels covered from each feeding point was 48 sq. ft., or an area equivalent to a space 8×6 ft., which is surprisingly small.

In range No. 6 it was known from observation and from the constant amount of bait taken that only one mouse occupied this territory. The amount of space covered during the night when this food jar was coloured was 42 sq. ft., which is nearly the same as the mean of feeding group ranges. Although it is dangerous to draw conclusions from this single instance, it is reasonable to suppose that the individual ranges of the other mice were much the same, and that therefore each feeding group range was covered fairly completely by all the members of each group.

Furthermore, since several of these group ranges contained more than one feeding point, and also since the group ranges showed a considerable measure of overlap, it is fairly clear that these figures indicate the minimum mean range for the house mouse. Otherwise not only would the distribution of consumption between the six points have been more regular, but the coloured faeces should not have reached to other food points. Therefore the ranges are not further compressible by the multiplication of food sources.

We had now established roughly the minimum range of the house mouse,

and further experiments were designed to throw light on the relationship of range size to the number of food sites available. Accordingly the number of food points was reduced from six to three, and the method of colouring each point in turn with gypsum and eosin was repeated. Results were as follows:

Area (sq. ft.) covered by mice feeding at point 1	= 68
,, ,, ,, ,, 4	= 67 (+20 up cellar steps)
,, ,, ,, ,, 5	= 50
Total area searched	185 (+20)

The areas covered from each point (mean = 62 sq. ft.) had not been greatly increased by the spacing out of the food points (apart from the extension of No. 4 due to unsatisfactory experimental conditions). This means that all the reduction of food points to three has done is to cut out the overlap in the feeding group ranges, so that each such range now contains only one feeding point. The number of feeding points is now just enough to supply the mouse population foraging in the normal way and their ranges have not yet been materially extended.

Finally, the food supply was reduced to one central point in the middle of the cellar and this was coloured with eosin. The red faecal pellets in this experiment were distributed all over the cellar, covering roughly an area of about 200 sq. ft. This shows that the mice quickly adapted themselves to the new conditions, since there was only a very slight drop (44·25 g. compared with 49 g.) in the total amount of food taken during the first night. Some must have extended their range considerably to reach the food.

The single food point was then moved for several days successively to each end of the cellar. The first change caused a considerable drop (41 g. to 19·5 g.) in the total amount of food eaten, so some of the mice were unable to adapt themselves to the necessary extension of their range within 24 hours, but within 48 hours the consumption was back to normal.

The following conclusions may be drawn from these experiments:

(*a*) Under conditions where plenty of cover and food are available, though not co-extensive, the normal daily range of a house mouse is small (of the order of 50 sq. ft.).[1]

(*b*) This figure is a minimum, and duplication of food sources does not subdivide the ranges any further.

(*c*) A number of mice may share a range, or rather their individual ranges may overlap. Toleration of such overlapping may come through the characteristic social structure and system of relationships known to exist among mice (see Allee, 1942). At a density of one

[1] This result has been confirmed by Young, Strecker, and Emlen (1950) who found that the mean distance of recapture of individuals in a free-living indoor population was 11 ft.

mouse per square yard, which was found in a grocer's shop at Oxford, some thirty mice instead of twelve would have been living together in this cellar.

(*d*) Where food is scarce or distributed less densely the range of house-mice increases accordingly. They adapt themselves to changes in the distribution of food points very rapidly.

(*e*) The upper limit of range size is not known.

4. OBSERVATIONS ON THE NORMAL DAILY RANGE OF THE HOUSE MOUSE

The observations detailed here were made in natural habitats, and they corroborate or extend the conclusions reached in the previous section. In an experiment in an Oxford grocer's shop and store eight bait points of dry rolled oats were placed. Each day those points from which bait had been taken were weighed and replaced, and those that were untouched were shifted to another part of the room. In this way an increase was obtained in the number of points visited by moving the bait into fresh ranges. The greater the number of bait points visited, the more bait was taken as shown in Table 2.

TABLE 2. *Parallel increase in total take and number of points visited*

	No. of points visited	*Total take per day (g.)*
Day 3	4	5·0
,, 5	5	6·5
,, 7	5	8·0
,, 9	7	8·5
,, 11	7	8·5
,, 14	6	7·6
,, 16	5	6·0

The figures in Table 2 indicate that the increase in active bait points meant that more mice were feeding: otherwise, if their attention was merely being divided, the total take would not have increased concurrently. Therefore, the ranges of the mice were sufficiently small to necessitate shuffling the bait sites in a room 17 × 12·5 ft. before the greatest number of visits was recorded.

Elton carried out a number of poisoning experiments in the same cellar which was used for the range experiments described in section 3 of this chapter. An unknown number of wild mice were living in the cellar at this time and a single bait point was placed on a ledge half-way down one side. After various poisoning trials, which were unsuccessful, a take of arsenious oxide poison bait equivalent to 3·2% of the prebait take was obtained and visits ceased for the next 4 days. However a female mouse with three young in the nest was then discovered about 13 ft. away from the bait box and

between days 5 and 11 of the experiment the postbait rose again. This showed that at least one mouse was living out of range of the bait box, and also that it fairly rapidly extended its range to occupy the ones left vacant by the mice killed.

A particularly informative experiment was carried out in the basement of the Department of Pharmacology in Oxford. This was designed to show more precisely than hitherto the way in which mice moved about a large area.

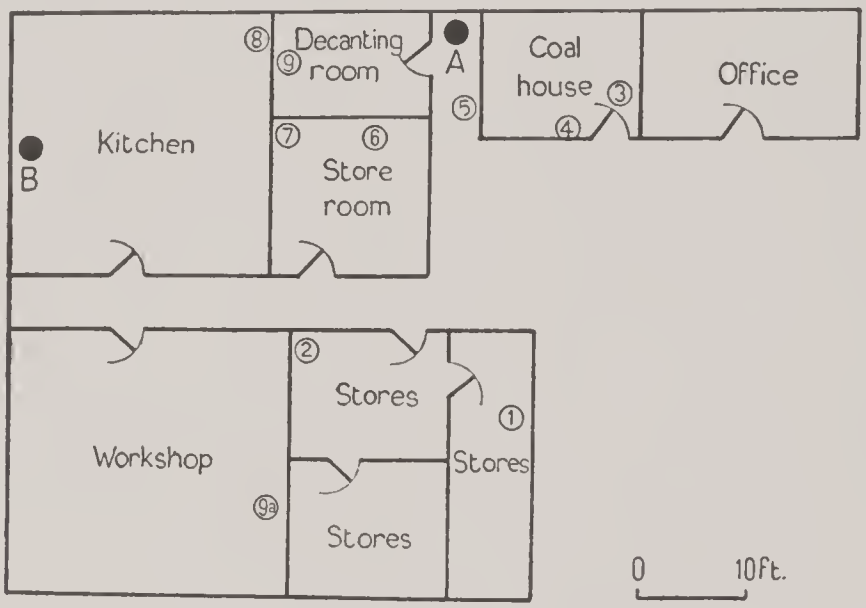

FIG. 3. Plan of Department of Pharmacology basement.
A, *B*, Main bait points.
1–9*a*. Subsidiary bait points.

The arrangement of the various rooms is shown in Fig. 3. The main sources of food were sacks of cubes (kept in the kitchen) for the tame rat stock and various scraps in the same place left over from cooking meals. Two main feeding points were established at *A* and *B* each with a surplus quantity of dry rolled oats. Prebaiting was continued at these points until a steady level had been reached and all the mice it was possible to attract were visiting regularly. For 6 consecutive days the daily amount of food taken was as follows (g.): 89, 93, 84, 84, 66, 80.

Nine subsidiary bait points were then distributed about the building as indicated by the figures on the plan (9 and 9*a* are alternative positions of one point). By this means it was hoped to detect by the increase or otherwise of the daily take whether additional mice were attracted. The rise in take to 128 g. during the 2 days after the change was so well-marked that there is little doubt more mice were successfully baited in this way.

By using the points *A* and *B* part only of the population would have been reached, although the amounts eaten suggested a good 'take'. Probably the extra points drew in half as many mice again. The extra take was distributed between points 2–5 and 8. The last would naturally attract attention being

in the same room as *B*, so that most of the newcomers whose ranges did not reach as far as points *A* and *B* probably came from the regions about points 2–4. One interesting thing about this test is that food was apparently scarce and separate from cover, so that conditions seemed ideal for drawing the mice to baits. In general the result emphasizes the need for multiplying bait points so as to reach the range of every mouse.

Further work was done upon the range of house mice by Elton in an Oxford grocer's store. His method was to place large numbers (30–50) of 0·5 g. piles of rolled oats all over a room and to observe the order in which these were taken from day to day. This was only possible with a small population of mice because otherwise all bait piles disappeared during the first night. The first experiment was done in a storeroom 18×20 ft., which had shelves and stores along two sides and other goods stacked all round the room on the floor; forty bait points were distributed about the room, and the next morning fifteen of these had been eaten. The mice on emerging from cover evidently started on the pile nearest to them and worked along eating at consecutive piles because the points that had disappeared were distributed in two groups of seven and six, each concentrated and near to one of the walls. Two points only were taken away from these areas. A subsequent experiment a fortnight later showed a very similar distribution, the only difference being that rather more points were taken.

Another experiment was done in a saddler's storeroom in the house next to the grocer's. There was practically no food here and cover was distributed along each of the walls and out in the middle of the room. Thirty-four bait piles of rolled oats were placed round the room and disappeared as follows (for details see Fig. 15, p. 153): after the first night 13, of which 7 were consecutive points in one corner and along one side, 4 were grouped together in the opposite corner, and 2 were isolated points, 1 of them in the middle of the room; after the second night 20, which cleared out all the rest of the points along the sides of the room and 5 of those in the centre; after the third night 2, right in the centre of the room farthest from cover. Immediately after this traps were put down and three mice were caught. The amount of food taken is roughly what three mice would eat. If they were the only ones present, then it is clear (*a*) that the mean area searched per mouse on the first night (when food was distributed all over the room) was of the order of 50 sq. ft., (*b*) that this area increased progressively on the second and third nights as the distribution of the food narrowed, and (*c*) that searching begins from a point nearest cover.

5. INTERNAL PRESSURE AND THE FORMATION OF NEW RANGES

Although the ranges of mice may overlap, and densities of one per square yard or five to a normal daily range are not uncommon, it is evident that natural increase, which under favourable circumstances may reach 6–8

litters per year (see Laurie, 1946), must force the mice to expand their ranges or seek new ones.

As an example of the speed with which cleared premises may be reinfested, the following control test carried out in a shop in the Oxford market may be quoted. This was a combined grocer's and greengrocer's, which together with a butcher's shop, which backed against it, formed the end of one block of buildings. There were three rooms: the shop (*c.* 16×12 ft.), the office (*c.* 12×9 ft.) and a smaller office above this. House mice were here in numbers and were running in all parts of the premises. Prebaiting was done with small piles of rolled oats (*c.* 1·5 g. each), a peak of twenty-two points cleared was reached in 9 days and poisoning was done on the eleventh day. The poison bait was taken well and ten corpses were found, yet on the twenty-second day the daily take of rolled oats piles was back to a level of nineteen. This could not have been due only to failure of poisoning because of the number of corpses picked up, and these would represent only part of the kill. During the space of 11 days, therefore, at least ten mice and probably many more had been replaced from neighbouring infestations.

Another experiment was done in a London warehouse by Watson and Perry. The main intention was to test the efficiency of direct poison-baiting for house mice, but the use of trace testing (with plaster of Paris patches) as an addition to postbaiting showed very clearly the progress of re-invasion. Fig. 4 shows part of the warehouse concerned: the main bulk of the goods (biscuits in sealed tins) was in the central area. Along the wall facing these was a stack of broken and defective tins in which was the main focus of mice. In the other two rooms on each side were similar stacks of tins, which were not so badly damaged, and hence the mice were not nearly so dense here. The whole area, including a distance of about 50 ft. into each of the side rooms was poisoned with sugar-meal and 5% zinc phosphide and the area was cleared successfully of mice. This was on 4 April; after 7 days the postbait in the two side rooms started to disappear and plaster of Paris patches showed that mice were moving in from these rooms. Six days after this they had penetrated into the main stack from each end (see Fig. 4) and 3 days later they were 10 ft. farther in.

Thus in 16 days the mice pushed forward their area of occupation 65–80 ft., a rate of 4 ft. a day. This can hardly be accounted for by internal pressure in the population, but, on the other hand, it was not a sudden invasion. It seems most likely that this steady progress was due to new mice unfamiliar with the environment gradually exploring and getting to know the area suddenly left empty by the poisoning.

Mice may also extend their ranges owing to hunger, so expansion may result not only from the actual density of the mice, but also from the density relative to the food supply. The cellar of a dry-cleaner's shop in Oxford was used for storing wrapped and labelled parcels waiting for delivery, and

mice were entering this cellar from a hole in one corner. Though there was no food, they were ranging all over the room and removing the labels to the great confusion of the business. Plain bait was provided and the mice immediately ate about 18 g. a day, which increased in 8 days to about 52 g. This means that a minimum population of fifteen mice (even if the bait was their only source of food) had expanded into this cellar in a week, so movement into new ranges may be quite rapid.

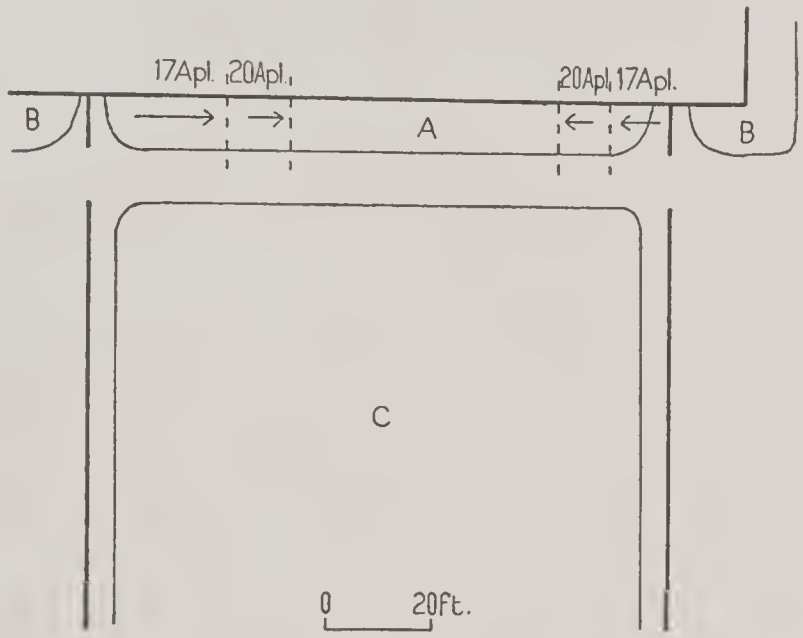

FIG. 4. Plan of warehouse used for field test on speed of re-invasion by mice.
A. Broken tins in which choice baiting and census baiting were done.
B. Few damaged tins only. Poisoning, post-baiting, and trace census were done here as well as in *A*.
C. Undamaged tins.
Interrupted lines mark limits of re-invasion.

From these examples we see that the conception of a range as extending and readjusting itself primarily from the exploratory drive in mice but modified in speed and frequency of occurrence by density and/or abundance of food and cover, is a fruitful one with considerable bearing on the results to be expected in poison trials.

6. VARIATIONS IN THE NORMAL DAILY RANGE

To avoid giving the impression that house mouse territories are definite and unvarying in extent when there is no particular pressure to change them, we quote the following observations on range variability.

Plain bait was put down in all the rooms of a grocer's premises. The figures given in Table 3 are for complete takes of 1 g. points of dry rolled oats. The different rooms are arranged in order descending from the top of the house.

These figures show that the mice transferred their attention from room

to room on different nights. The second floor room never again reached so high a figure as it did on the first night, while the first floor back rose to a peak on the second night. The cellar, on the other hand, remained low until the last day, when fifteen points were cleared.

TABLE 3. *Distribution of bait 'take' by mice from day to day (figures = 1 g. piles of rolled oats)*

	Day 1	*Day 2*	*Day 3*	*Day 4*
Second floor . .	16 (46%)	3 (12%)	10 (18%)	13 (18·5%)
First floor back .	8 (23%)	12 (48%)	20 (36%)	25 (36%)
First floor front .	6 (17%)	5 (20%)	12 (21%)	11 (15·5%)
Shop . . .	..	..	7 (12·5%)	6 (8·5%)
Cellar . . .	5 (14%)	5 (20%)	7 (12·5%)	15 (21·5%)
Total. . .	35	25	56	70

It is evident that this represents normal variation in range and, although a mouse may not necessarily search a larger area on one night than on another, it may search a slightly different one. This process may be accentuated in an environment such as this, where the main cover is the walls of buildings and the difference between entering one room or another may only be a few feet to the mouse.

In another instance mice came out of a cupboard into a room in an Oxford house and bit a hole in an expensive carpet to get out under the door. Plaster of Paris was put down inside the cupboard together with bait and the doors were jammed together tightly. For a week no trace of mice was seen and it was thought that they must have been killed by the poison campaign going on in the rest of the house. On the eighth day, however, the same trouble recurred and the carpet, which had been mended in the meantime, had another hole bitten in it. On this occasion they had got out of the cupboard at the top of the door, where there was an unsuspected crack. The plaster of Paris revealed that they had not entered this cupboard in the interval and that this area only occasionally came within their range.

7. OBSERVATIONS ON DISCONTINUOUS RANGES

Nearly all house infestations, such as the above, are examples of discontinuous ranges in which cover is separated from food. For convenience, however, only cases where mice must make a considerable journey between cover and food supply will be considered under this heading. This is perhaps making an artificial distinction where in fact there is a complete gradation, but the existence of discontinuous ranges is so important from the practical control point of view that the real discontinuity ought to be recognized as soon as possible in order that the appropriate measures may be adopted.

A house mouse infestation in a M.O.F. buffer depot, which contained

sacked oats, illustrates this situation well. Several floors of the warehouse were almost completely filled with stacks of sacked grain, and on the top story were two large inter-communicating rooms, one of which was empty: the other contained a small stack of about eighty sacks placed in a corner near the door. Mouse damage in this stack was bad and an attempt was made to bait them with points consisting of dry rolled oats (50 g. at each) distributed on and near the foot of the stack. One of these bait points at the foot of the stack was adjacent to the doorway leading into the empty room, and it was quickly noticed that the bait here was completely taken every day, whereas other points on and about the stack were indifferently used.

Many of the mice, therefore, were not living in the stack, and investigation revealed a runway which led along the wall of the empty room to a point half-way down its length where there were several holes and crannies in the skirting board and the wall. These were quite 10 yards away from the oat stack.

Interception of the mice along this runway sent up the daily take of prebait quickly and a peak was reached in which over 80 g. were taken from points away from the stack and only 20 g. from the stack itself. There were also mouse holes on the opposite side of the empty room, but intercepting points showed that no mice came from this direction.

It seems remarkable that in face of eighty sacks of grain half-spilled on the floor a mouse should be diverted to a small bait box, but this no doubt illustrates the limitations of its vision. Waugh's experiments (1910) suggest that mice only distinguish objects at distances up to 15 cm., so that successful baiting is more a question of correct siting than of providing counter attractions to the food already there in abundance.

After the experiment was finished the stack was broken down and the mice which ran out were killed; they totalled forty-two. From the peak prebait figure (80 g.), even if we reckon that all visiting mice were living only on the bait, a minimum of twenty-two must have been coming to the stack to feed (a mouse eats *c.* 3·6 g. of rolled oats a day), and almost certainly many more were concerned. Thus half as many mice at least lived outside the stack as inside and they were making a regular journey of 10 yards or more from cover to food. Even longer journeys must have been made by a mouse whose nest was found by Elton in a buffer depot 22 yards from the nearest food.

A final example will show that a shop infestation may have a similarly discontinuous range, though such cases are not nearly so easy to diagnose.

The premises of a confectioner in Oxford consisted of the shop in front and a kitchen and store cupboard behind on the ground floor: on the first floor was a front room and a side room, both over the shop, and a back room over the kitchen. Mice were running throughout the premises and small bait points were placed all over the building. The results of this baiting seemed to show that mice were coming out at two main points: one at

the front corner of the shop under the window display counter and another under the step leading down into the first-floor back room. Baiting was finally concentrated at these two points, which were 30 ft. apart in a straight line (not allowing for difference in height).

When poison bait was put down, however, it was only eaten at the point in the corner of the shop. Postbait showed that the whole building was now cleared, so that all the mice must have been coming in from the one point, and their range must have extended for at least 30 ft. after they had emerged into the shop.

How much larger the areas covered by mice in these cases of discontinuous ranges are than the 50 sq. ft. estimated for a (more or less) continuous range in the cellar experiments is not known. Presumably the connexions between the separate parts of a discontinuous range will be confined to narrow runways, so that there is no reason to suspect any great increase in the total area searched.

8. OBSERVATIONS ON HOMOGENEOUS ENVIRONMENTS

At first sight environments such as corn-ricks, stacks of grain in bags, and so on seem to be places where the range of mice would be at its minimum. There is negligible movement outside such units as these stacks, and, since densities are often very high (thirteen per cubic metre were recorded in one rick) here surely mice will not need to range over more than a few square feet.

However, as already noticed in the cellar experiments, the figure of 50 sq. ft. was a minimum one and a number of mice would share and not subdivide this area. Consequently even under conditions where cover and food coincide and the mice have abundant food all round them, there is a considerable amount of movement about the stack.

A M.O.F. buffer depot near Oxford contained at one end five stacks of bagged oats with stacks of flour adjacent, and Southern and Rzóska carried out intensive work on baiting at these stacks in the summer of 1943.

Preliminary trials with dry rolled oats placed round the edges of the stacks gave very poor results, and the impression received was that most of the mice never ranged as far as the outside of the stack. However, when the bait was changed to moist sausage-rusk, fifty or more points (*c.* 3–4 g. at each point) at one stack in one night were frequently eaten. From this it seemed that there was far more movement within the stacks than had been suspected, and one or two experiments were devised concurrently with the poison trials to throw light on how much this movement was.

The first experiment was done upon a stack of bagged oats (dimensions $37 \times 32 \times 6$ ft. stacked in two layers of sacks placed on their ends and a top layer on their sides) around the outside edges of which plain baits had been placed daily for about a week. When this daily take had settled to a fairly level figure, an area was marked out on top of the stack

leaving an outer margin four bags wide. Inside this rectangle with an area 25×20 ft. thirty baits were dropped down in among the sacks to test whether this additional food inside the stack would decrease the amount taken from the edges. The result was a marked drop in take from the outside, as shown in Table 4. Subsequently a similar test was made on the same area of the stack using poison bait.

TABLE 4. *Temporary reduction of marginal bait-take by baiting centre of a stack*

Day:	*6*	*7*	*8*	*9*	*13*	*14*	*15*	*16*
			(30 plain baits extra dropped inside on day 7)					(15 poison baits inside)
No. baits taken .	36	39	28	31	38	40	45	37
No. partially eaten . .	4	4	3	3	4	5	2	7
Total . .	40	43	31	34	42	45	47	44

These results show that mice living normally 6 ft. inside a stack were in the habit of visiting the outside to take the baits placed for them. The amount of the decrease (25%) should probably not be given too much significance, but it shows roughly the order of movement within 6 ft. of the stack margin.

The poison bait result is not very clear. There was a slight drop which probably indicates that some of the mice living inside and visiting the margin had sublethal doses, especially as the number of partial takes increased, but the poisoning trial was a failure and there was no continuation at a lower level of marginal takes as had been hoped.

Subsequent to this, another similar test was made upon a neighbouring oat stack, which was irregular in shape, so that one 'wing' of it could be left without extra baits as a control to the main part of the stack, where inside baiting was done (see Fig. 5).

Unfortunately the rates of take between *A* and *B* were not noted until the inside baiting began, but, since the baits were distributed regularly round the margins and no part showed marked and continuous takes more so than any other part, we may apportion the total take according to length of margin. The area *A* has roughly three-tenths of the whole margin of the stack, so that we may suppose the take on day 40 to have been 12 wholly and 4 partially taken in *A*, and 29 wholly and 9 partly taken in *B* (see Table 5).

The effect of the inside baiting is clearly shown. The actual take in *A* on day 41 corresponds very closely to the calculated amount for day 40, whereas in *B* there was a total drop of about 30% in points visited, while many more were only partly eaten, which had been wholly eaten before.

Thus it can be seen that the population living in *A* was totally unaffected by the inside baiting. Those living in *B*, however, were considerably

affected. This result is not badly out of agreement with the idea that mice move about an area normally not much greater than 50 sq. ft.

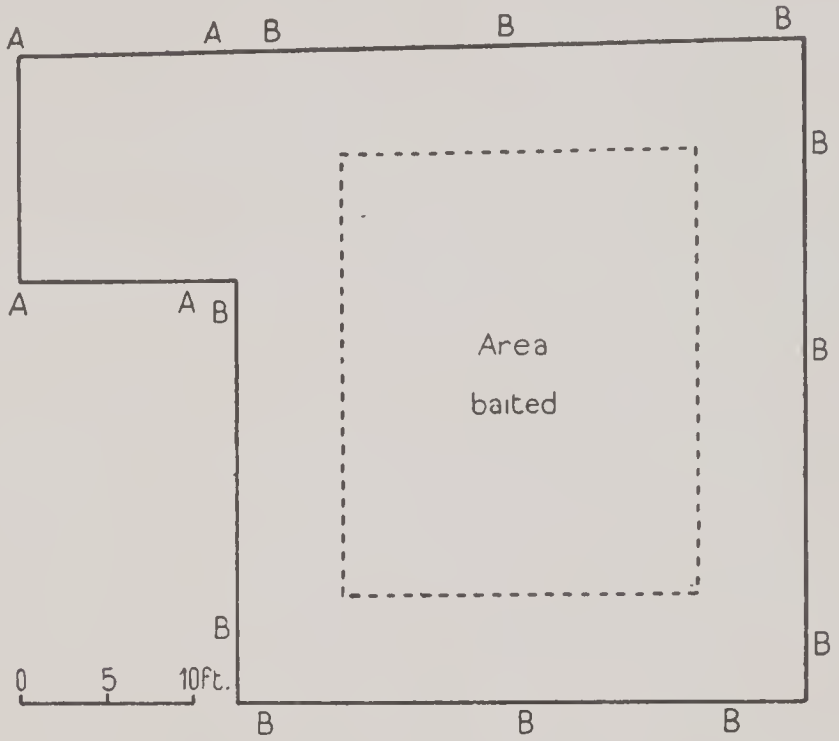

FIG. 5. Plan of stack of bagged oats where inside baiting was done.

Removal of a certain number of mice with traps from this stack and observing the drop in mean daily take of bait suggested that the population was of the order of 60–70 mice, when the above experiment was done. This means a density of about one mouse to every 2 sq. yds., so that two or three mice on the average would have overlapping ranges. This corresponds with the social arrangements in the cellar experiments.

TABLE 5. *Effect of baiting the centre of a stack on take at the margins*

Day:	*40*			*41*		
	A	*B*	*Total*	*A*	*B*	*Total*
				(50 baits dropped in central area)		
No. baits taken	12*	29*	41	16	11	27
No. partially taken	4*	9*	13	5	14	19
Total	16*	38*	54	21	25	46

* = estimated (see p. 28).

Generally one may conclude that the normal range of a mouse is not greatly different in homogeneous environments and there is no great barrier to baiting a great number of the mice in such places. This of course only considers stacks of the order of size of those discussed in this section. Much larger ones, or ones in which the margins are obstructed (such conditions are found in cold stores) will obviously be more difficult to deal

with, since a rapidly increasing percentage of the population will have ranges that do not reach to the margin.

9. CONCLUSIONS BEARING UPON CONTROL

The most important conclusion to be drawn from the considerations advanced in this chapter is that different infestations of house mice will all have slightly different reasons for their existence and will take different courses, if left to themselves, according to the variation in environmental factors. Climate will impose variation, first of all directly by making shelter necessary from heat and cold, secondly in an indirect way via the type of food supply that is best grown in the area concerned and the local methods of storing it; and thirdly by seasonal changes which make an alternation of habitat necessary for the mice. Further than this the micro-climates of different habitats will provide special conditions, which must be taken into account: the warmth of corn-ricks, shelter from air movements, which would cause loss of body heat, in many buildings, and from insolation, all these factors will play their part in determining the success or otherwise of a colony and the time for which it can maintain itself.

The type of food available is important, doubtless to a far greater extent than we realize at the moment. Most foods stored in bulk will be less satisfactory as a diet than the varied menu of a smaller store. The importance of this factor can be recognized better now that we understand how circumscribed is a mouse's territory. A food depot may have stacks of many kinds of goods, but it is unlikely that more than a few mice would move regularly from one stack to another. It has been stressed that mice *can* maintain themselves in reasonable health on quite a poor diet and will even produce litters at a high rate, but Watson's experiments (1937) show that the vulnerable period comes during a mouse's infancy. A very high mortality in the nest or just after leaving the nest, whether through litter-eating or any other agency, will quickly check the rate of increase of a population. The effect of this may be seen in many ricks where mice are very dense.

Naturally both these factors of micro-climate and food supply will interact: the tolerance level to cold will be reduced unless plenty of food is available; the tolerance level to heat will likewise be reduced unless water can be found, and this again becomes a more serious factor, when the smallness of a mouse's range is remembered. Under normal conditions most of the mice in a corn-rick will probably find sufficient water for their needs in the dew or rain on the rick surface, but after a run of warm, dry nights the situation might materially alter for the worse.

Conditions which best suit the rapid increase of mice will be equable temperatures, a mixed diet with adequate water, and undisturbed cover for escaping from enemies and rearing young: furthermore the nearer cover is to food supply, the safer will be the mice.

Under such conditions it may seem remarkable that, when a population has been built up to a density of, say, one mouse per sq. yd., increased contacts should not result in a greater mortality from fighting. The cellar experiments upon ranges have shown that a number of mice may happily share a range, and the social organization that this implies has been elucidated by recent work on social psychology. Some of the results of investigations on tame mice have been summarized by Allee (1942), who shows that in a group of mice living in close contact an order of dominance is evolved according to the innate aggressiveness of each mouse in relation to the others. After so many contacts between two individuals the one which is regularly worsted will then give way to the other without a struggle, and once this social order has been fought out, the mice live together in comparative amity with only occasional readjustments. Thus the 'ceiling' for density is pushed up higher and the controlling factor is more likely to be food supply.

With these considerations in mind one can easily perceive that different infestations will need different treatments for control. First the type of food supply and physical factors of the environment need investigation. Next the spatial relationships of the habitat must be made out: if cover is separated from food, the connexions between the two must be identified, so that baits can be placed in intercepting positions. On occasions it may be possible to adopt the simpler method of removing the food or the cover or both, or at any rate giving the cover a 'shaking-up' so that the mouse's defensive system may be upset and it will lose time (reproductively speaking) in reorientating itself.

Since, however, conditions are usually heavily in favour of the mouse, further information and adjustments in technique will be necessary. It is not always possible to treat the whole of a population at the same time, so that once control of part is achieved a system of maintenance must be devised. For this it is necessary to know what is the average rate of reinfestation. It is rarely possible, in habitats where cover and food supply are intermixed, to exterminate the local mice in one operation; therefore the conditions which limit the timing and baiting methods of a second or even a third treatment should be known.

Most of these difficulties are treated at length in following chapters. It will be sufficient at the moment to have realized that each infestation is potentially a new problem and should be treated as such until evidence is produced of the contrary.

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3

THE HOUSE MOUSE AS A PEST

1. DAILY CONSUMPTION OF FOOD

OUR first need is an accurate figure for the daily consumption of food by house mice on which to base any calculations of the total amount eaten by populations. Two main purposes have been served in the Bureau's research upon house mice by figures of this kind: in the first place there is no other way of obtaining even an approximately valid estimate of, for example, the total damage done in a corn-rick by a population of known size; in the second place it forms a criterion for gauging the amount of bait needed when poisoning mice. Many practical workers are misled by the small amount of food taken by mice and tend to believe that their prebaiting or poison baiting has been unsuccessful, where the contrary is the case.

Conversely from the amount of prebait taken we may form a rough idea of the size of population concerned. With house mice it is not possible to make as accurate censuses in this way as may be done with brown rats (see Vol. 1, Ch. 4), since mice can rarely be drawn completely away from their own food supply. However, even a minimum estimate of a population is often valuable, and, in cases where the 'natural' food supply is scanty, such an estimate draws very much nearer the truth.

The figures given here for daily food consumption are based on a long series of experiments, mostly carried out for other purposes, and analysis of these has yielded results which are worth giving in some detail.

The mice used were all obtained from corn-ricks at threshing and were kept together in large cages with surplus supplies of rolled oats or whole wheat and water until they were needed for a special purpose. They were then removed one by one, weighed, sexed, and placed in separate cages and the daily consumption of food weighed every morning at 10 a.m. The figures for the first 2 days after removal from the stock cages were discarded, since it took about this time for the mice to settle down to a steady rate of eating. Unlimited water was supplied in the small cages as well as in the stock cages. Stocks of mice kept in this way for periods up to 4 months were perfectly healthy and vigorous at the end, so there is no reason to think the consumption is in any way depressed by their condition. Mice used in the small cages for experiments lasting a week or more usually lost 2–3 g. in weight during the experiment but this may in part have been caused by their being given no hay or chaff as cover. No mice that had been subjected to poison tests are included in these figures.

The foods used in these experiments were (1) whole wheat, (2) oats

husked and crushed (equivalent to 'porridge' oats, and referred to throughout this volume as rolled oats), and (3) sausage-rusk mixed with its weight of water. Weighing of the first two was straightforward. In the case of sausage-rusk mash the residues were dried each morning, weighed, and 10% added to make up for the original water content of the dry rusk. This figure was then subtracted from the original weight of dry rusk given and the daily consumption expressed in terms of dry weight.

Most experiments were done at room temperatures or in outdoor sheds during the summer. Some were done in a cellar during the winter, through which ran a number of pipes belonging to the central heating system, which made the air warm and dry. Records for a week with a hygrothermograph gave a mean temperature of about 21° C. and relative humidity of under 40%. All experiments done under these conditions were upon rolled oats and the results have been treated separately in the analysis since the consumption of food was considerably less.

The weights of all mice used are given in an appendix. All of them were adult (10–27 g.), and testing for regression of consumption on weight gave a non-significant result. The figures (especially for sausage-rusk mash and whole wheat) suggest a slight degree of relation between weight and consumption, but this could only be confirmed by data from lower weight groups. Since the figures considered would only cover the last section of a weight–consumption curve, where it may be expected to flatten out, it would clearly be difficult to prove the main trend from this section only. With the brown rat, however, by taking animals over a wider range of ages (comparatively speaking) a significant relationship was established (see Vol. 2, Ch. 6).

The figures given for consumption in the appendix are means for each individual mouse, and the number of observations, from which the means were calculated, is stated in the second column.

For each food, analysis was carried out of variance between the figures for males and females and in no case was any significant difference detected. In the case of sausage-rusk mash an analysis of covariance between weights and consumption was carried out and it was clear that variance in weight had no effect on the figures.

The following means with their standard errors may therefore be given for each food:

Whole wheat	$3{\cdot}400 \pm 0{\cdot}224$ g.
Sausage-rusk mash (dry)	$3{\cdot}619 \pm 0{\cdot}094$ g.
Rolled oats (normal temperature)	$3{\cdot}552 \pm 0{\cdot}107$ g.
Rolled oats (high temperature)	$2{\cdot}492 \pm 0{\cdot}147$ g.

Analysis of variance between the different kinds of food showed no significant differences under similar conditions of temperature, but in the case of rolled oats under the two conditions of temperature the difference is clearly significant ($t = 5{\cdot}044$ for 53 degrees of freedom). This confirms

previous experiments with brown rats, in which animals living out of doors had significantly higher mean rates of consumption than those kept in an animal house.

Since the sausage-rusk was given to the mice mixed with its own weight of water, it follows that the daily consumption of the resultant mash is rather more than twice as much as the mean consumption of a dry food like rolled oats or wheat (7·238 g. compared with 3·552 g. or 3·400 g.). For the brown rat it has been shown that the daily consumption of moist sausage-rusk is exactly twice that of wheat.

Data were also obtained on the daily consumption of other foods, but, since none of these proved satisfactory for one reason or another as regular baits, the figures are small and give no more than a rough idea of the amounts eaten.

National flour. This food was favoured at first in experiments because poisons mix so satisfactorily with it, but it was finally discarded on account of the difficulty of measuring what is eaten. If flour is provided in an open jar, it is carried owing to its rather sticky nature all over the cage on the feet and fur of the mice; some attempts were made to produce a hopper, which would circumvent this trouble, but the mice continually raked out the whole contents of the hopper, so that the results were worse than with an open jar. From the only six observations that can be considered satisfactory the mean daily take of national flour was 2·9 g. It is certainly not an unpalatable bait to mice, but it is probable that its dry nature provides some mechanical bar to its being taken in large quantities.

In spite of this, national flour with or without 10% of castor sugar mixed with it was used in a number of field experiments with success. In the open mice do not scatter it so much as in a small cage.

Dried breadcrumbs. This was an unsatisfactory bait, and its use was soon discontinued. From fifteen observations the mean daily consumption was 2·77 g.

Dry sausage-rusk. This was quickly discarded in favour of the moist rusk. It evidently presented the same mechanical difficulty to eating as national flour, since the mean consumption (2·2 g. from eighteen observations) was a great deal less than the dry weight eaten, when water was mixed with it.

Bread mash. This was the first wet bait tried, and was made by adding to dry bread crumbs about 3 times their weight of water. It is troublesome to prepare this bait and it soon goes stale and sour, so that sausage-rusk was at once adopted when it became available. From thirty observations the mean daily consumption was 8·93 g. but this quantity needs correction by an evaporation factor. Control tins of bait lost about 20% of their weight in 24 hours, so that a figure of something like 10% needs to be deducted.

These figures show that, although the quantity of food eaten daily by a house mouse seems so small, it represents a larger amount in proportion

to its weight than that eaten by the rat. This is to be expected in view of the mouse's smaller size. The figure for daily consumption is equal to about 10% of the body weight in the case of a medium-sized brown rat (see Vol. 2, Ch. 6), but to more than 20% in the case of the house mouse.

2. FOOD TAKEN BY HOUSE MICE UNDER NATURAL CONDITIONS

The staple foods of house mice are cereals of all kinds, and it is through such goods as these that mice inflict the gravest economic losses upon man. This is natural for two reasons; because these basic foodstuffs are produced in larger quantities than anything else in this country, and because they have to be stored in such a way that they are vulnerable to mice for long periods and form ideal harbour for them. Wheat, oats, and barley in grain are all attacked in the order listed, but in addition there is a big loss from sacked flour, particularly when it is stored in large quantities. Rye is an uncommon grain in Britain and is usually threshed early, but may be attacked like any other cereal if it is stored for long in warehouses. Among other sacked products the only instance of serious damage to bulk stores encountered during the Bureau's research has been to grass seeds. This is on a very small scale, but high quality seed kept for the next season's sowing is expensive. We never once recorded any damage to legumes, and a choice test of various foods done in a grocer's shop by Elton (see Table 29, experiment 1) confirmed that this class of goods was unappetizing to mice. Damage to meat in cold stores is another fairly large item to be entered against the mouse, but is obviously concentrated in a few areas.

Damage by mice to processed goods cannot be measured purely by quantity, since there are all gradations in value according to the costs of processing, packing, and transporting. A complete catalogue of the goods which house mice will eat would be endless because they will tackle almost anything edible when they are really hungry. The following list, therefore, includes only typical examples of the kinds of goods most frequently damaged.

The variety of goods is probably greatest in grocers' shops and stores, and among the instances of damage observed the following trends can be distinguished: first to be attacked are cereal goods of all kinds from those that are kept in fairly large quantities, such as rolled oats, oatmeal, whole and ground rice, flour, macaroni and vermicelli, pudding mixtures, custard powders, and biscuits, to those that are kept in small packets, such as animal foods, bird mixtures, breakfast cereals, and so forth. In a second class come the goods containing fats and proteins: cooked meats, butter, margarine, lard, the wax of candles and tapers, soap, glue or gum (often from the back of labels), and various kinds of nuts. Finally, there is the class of goods which seems to be supplementary to the main diet of house mice: sugar (only rarely), chocolate, and a wide range of dried fruits and preserves.

Mice will often nibble succulent foods for the sake of the water contained, e.g. melons, tomatoes, and apples, while instances are recorded of mice climbing up and eating hot-house grapes. Need for water is probably also the reason why mice will eat the milky heads of young corn and bite into the stem while it is still green. Many rather curious additions to this list could be made, such as the ingenious mice that were able to open a hen's egg, and others who pulled the drinking straws out of children's milk bottles to lick off the remaining milk.

Among all this remarkable medley of diet, which man has arrayed for mice to choose from, we can discern the original tastes persisting. Wild mice are mainly granivorous and do not live on herbage like many of the other small mammals, and consequently they are adapted to need only a small amount of water. This means they can live in dry places on a diet mainly of cereals or cereal products only taking fats and proteins in a secondary way. Cold-store mice are a notable exception to this.

3. INCIDENTAL DAMAGE

Damage by house mice, especially in houses, is often incidental to their pursuit of food. Much is done simply in getting at food, e.g. cartons are torn, waxed wrapping paper is gnawed, holes are bitten through sacks, and cellophane or cardboard covers to jam jars are pierced. When they eat the labels off goods, presumably for the underlying gum, they may cause great confusion owing to the lack of other identification marks.

Even more damage is done in search of nest material. Mice will take almost anything that is capable of being shredded for nesting, though the most usual substances are paper, sacks, and fabrics of all kinds, including clothing. Furthermore, the siting of nests may imply damage, since mice frequently burrow into the middle of cheeses, sacks of flour or sugar and so on, and make their nests at the end of the burrow.

Much of this kind of damage is done because of the scarcity of suitable materials for nest building in some habitats. In one M.O.F. buffer depot the main infestation of mice was in stacks of bagged flour; since these bags were linen ones the mice would not use them and instead travelled many yards to a stack of coffee, which they did not inhabit, to tease up the sacking and carry it back to the flour. In another buffer depot, which had recently been cleared of sacked oats, the remaining mice fell to damaging the sacks in which peas were stored, though they were never known to have eaten any of the peas. The confusion was great owing to the way in which the peas poured out of the holes.

Finally, mice will soil and make unfit for human consumption a far greater amount of foodstuffs than they eat. Food contaminated by mouse droppings is easily discerned and may, or may not, be condemned; contamination by urine is not so noticeable. Dangers to human health from this kind of thing are obvious, though not easy to establish by concrete

cases. Leslie (1942), however, quotes instances where contamination of food by mouse droppings was responsible for death from *Salmonella* poisoning.

This section may be not inappropriately concluded by quoting from Elton's notes on a high-class grocer's storerooms in Oxford.

In one room sacks of rolled oats and oatmeal were often torn by mice, with consequent bleeding on to the floor. Rolled oats was also kept in a cylindrical wooden bin, but the top was ill-fitting and mouse pellets were abundant in it. One rolled oats sack had a tunnel made by mice one foot into the centre. A sack of ground rice was similarly damaged. Four or five mice were found inside a 2 cwt. sack of Demarara sugar. Cartons kept on shelves in the shop were reported often gnawed and the contents eaten: Scott's (i.e. rolled) porridge oats, shredded wheat, best ground rice, &c.; also dried figs in sacks; almonds in their skins; two 4 lb. cartons of Tate's castor sugar; paper bag of flour and a sack of flour; lard left exposed or in paper overnight; 2 lb. packets of margarine partly eaten. A very big item is damage to jam, marmalade, and honey stored in paper-topped jars, often 7 lb. capacity. The papers get torn when jars are shifted and sometimes jars are cracked in transit or handling. The following items were noted: 7 lb. marmalade jar with the top torn, mouse entry within a few days and an accumulation of droppings; mice visiting two 5 lb. jars of strawberry jam; four 7 lb. honey jars left in store, broken in transit, leaking; one 7 lb. jam jar, broken in transit, oozing on to floor; three large raspberry jam jars with paper tops entered. One 7 lb. raspberry jam jar already entered and a good deal of the contents eaten by mice was being left so as to keep the mice from attacking new ones.

Such comment on a single shop illustrates the catholic tastes of the mouse and the constant drain upon the nation's economy which they cause.

4. QUANTITATIVE LOSSES INCURRED

Accurate figures about this are difficult to obtain. House mice are often wasteful eaters and, when tackling a plentiful store of grain, their method is to bite out pieces about 1–2 mm. long (see Kemper, 1940), in which process they drop many shreds and often discard the grain before it is half finished. Since the wastefulness associated with this way of eating may vary according to how much grain is present, how much the mice are disturbed, and how far dropped pieces are recoverable, no standard figure can be applied as a correction to the known daily consumption.

Estimates based, therefore, upon mean daily consumption and numbers of mice known (within certain limits) to be present for a fixed time will be minimum estimates, since no account of waste can be taken. Some calculations presented by Elton, based on the survey he made of corn-rick infestations in many parts of England during the recent war (full details are given in Vol. 2, Ch. 11), suggest that during the months of January, February, and March for every 100,000 ricks standing at the beginning of the period the loss from house mice will be about 5·09 tons of grain per day.

A more empirical method, almost as unsatisfactory, was employed on threshing results at ricks near Oxford and is described in greater detail in Southern and Laurie (1946). Threshing separates the different categories of damage with fair success. The millable grain comes out from the largest end of the sieve and generally has few damaged grains in it. Next comes the tailings, consisting of a small portion of undersized grain and a large portion of grains diminished by nibbling, together with a fair amount of mouse droppings. Lastly there is the 'dust', which in a mouse-free rick is composed mainly of weed seeds, but in an infested one of droppings and the finer particles of 'kibbled' or bitten-up grain. In a bad rick this may run to several sacks, and is an impressive reminder of the amount of grain that has been put through the 'machinery' of the mice.

TABLE 6. *Percentage of tail corn in mouse-infested ricks*

Locality	*Crop*	*Date threshed*	*No. of mice*	*Yield (in sacks)*		
				Millable	*Tailings*	*Tailings %*
Begbroke (2 ricks)	Barley	14 and 18 Mar.	*c.* 30 in each	180	10	5·5
Yarnton (9 ricks)	Wheat	Mar.	*c.* 50 in each	422	4·4	0·96
Begbroke (3 ricks)	,,	15–17 Mar.	*c.* 60 in each	170	6	3·5
Hampton Poyle	Barley and oats	25 Feb.	75–100	12·5	1	8·0
Kirtlington	Wheat	3 May	250–300	64	2	3·1
Cassington	,,	3–5 June	250–300	45	1·5	3·3
Kirtlington	,,	1–2 May	300	70	3	4·3
Sutton	Oats	8 May	331	59	4	6·4
Botley	Wheat	29 July	424	65	2	2·7
Cote	,,	15–16 July	800	50	6·5	13·0
Sutton	,,	21 Apr.	996	20	4	16·6

The tailings and dust give an index to the amount of grain damaged. How much grain has disappeared can only be measured, when two comparable ricks are threshed at different times and by the same threshing tackle. The only satisfactory instance which came to the notice of the Bureau was of two oat-ricks in Berkshire. One of these was threshed in October shortly after it was built and yielded 107 sacks of millable corn and 4 of tailings: the other rick was threshed in the following July and yielded 99 sacks of millable grain and 14 of tailings. The deficit in gross weight for the later rick was 16 cwt. (7 sacks), equal to 6·4% of the earlier rick, to which must be added the fact that a further 22½ cwt. (= 10 sacks) of tail corn was produced, which for milling purposes must be counted as loss.

If we take as the mean daily consumption of a mouse the figure of 3·6 g. quoted for rolled oats on page 34, the total loss of 16 cwt., or 1,793 lb., in

9 months is equivalent to just over 800 mice living in the rick the whole time. This figure is rather high, and the difference may be made up by a few rats living in with the mice. It is interesting to see that loss from damage is actually greater than loss from eating, and this is perhaps about the usual rate of waste caused by mice.

Table 6 (reproduced from Southern and Laurie, 1946) shows that, although there is a general tendency for older and more heavily infested ricks to yield a higher percentage of tailings, this is much obscured by variation in the different threshing machines.

These assessments of damage have been made upon types of food that afford the least difficulty in calculation. Damage to processed goods may be even greater, if the value of the goods is taken into account, but it is obviously impossible to give any precise figures.

5. THE HOUSE MOUSE AS A CARRIER OF DISEASE

A number of diseases may be transmitted to man by the house mouse, in fact most of the organisms carried by rats may also be carried by mice. The incidence of infection is, however, far less in the latter. In the case of plague (*Bacillus pestis*) there is no doubt of the susceptibility of house mice: Cleland (1918) reports that in Australia between 1902 and 1912 261 mice of those examined were found to be infected; there are also positive reports from several places including Calcutta (Hossack, 1907) and Peru (Bohec, 1933), and Booker (no date) considers it possible that house mice form a link in South Africa for transmitting the organism from veld rodents to those inhabiting houses. In spite of this, most authorities are agreed that the house mouse plays little part in the dissemination of plague. Much the same thing applies to typhus, leptospirosis, tularaemia, and so on.

Probably the most serious thing that house mice do is to spread *Salmonella* organisms (generally covered by the rather vague term food poisoning). The danger here is twofold: in the first place many mice are naturally infected by this organism, and since it is found in the intestine, it is easy for food to be contaminated by faeces. In the second place many of the cultures sold for rat and mouse extermination (so-called 'virus') contain strains of the two main species, *enteritidis* and *aertrycke*, which may be spread by the mice not only from faecal infection, but also by walking over the baits that are laid (for a discussion of the strains used see Leslie, 1942). Many cases of illness and death have been reported, which are probably traceable to this cause and some are apparently well substantiated (see Jones and Wright, 1936, and for further references Leslie, 1942).

The only other disease which can definitely be attributed to house mice is a favus or ringworm, practically always the species *Achorion quinckeanum*. Its incidence is uncommon, but Hull (1941) mentions that in Switzerland

certain houses become known as 'favus houses' on account of the persistence of the infection, which is undoubtedly maintained by mice. In other instances outbreaks have been associated with mouse plagues; Place (1917) instances such an outbreak in Australia coinciding with the vast numbers of mice that overran the grain belt during the last years of the First World War.

The economic importance of house mice as carriers of disease is small compared with their attacks upon our food resources. Nevertheless they are not to be neglected, if only on account of the ease with which they can and will spread to all parts of the earth inhabited by man. While transport was by sea the rat and the mouse advanced side by side; in aeroplanes mice will have a decided advantage.

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APPENDIX

Data on which figures for food consumption are based

TABLE A. *Sausage-rusk mash*

Males			*Females*		
Weight (g.)	*No. of observations*	*Mean consumption (g.)*	*Weight (g.)*	*No. of observations*	*Mean consumption (g.)*
11·5	2	3·6	10·0	1	4·7
18·5	2	4·2	11·0	1	4·1
20·5	2	3·2	11·0	1	4·6
18·5	2	4·6	12·0	1	4·0
24·5	2	4·1	14·5	1	3·9
13·0	1	4·3	16·0	1	4·8
18·5	1	4·4	13·8	1	2·1
17·5	1	2·8	14·5	1	3·2
21·5	1	3·7	17·5	1	3·0
13·0	1	3·8	19·5	1	3·0
13·5	1	2·8	13·0	1	3·8
15·0	1	3·2	11·5	1	2·1
17·0	1	2·9	13·0	1	3·2
17·5	1	2·7	15·0	1	3·2
19·5	1	4·2	16·5	1	4·3
22·0	1	5·6	12·5	4	4·1
23·0	4	4·3	19·0	4	3·5
14·0	1	2·9	24·0	4	3·5
17·5	2	3·8	25·0	3	4·2
18·0	2	3·4	24·0	3	4·8
18·5	2	3·4	22·5	3	3·4
19·0	1	3·0	20·0	3	3·3
			14·5	3	2·9
			12·5	3	3·2
			12·0	3	2·3
			13·0	2	3·1
			17·0	2	3·5
			18·0	2	4·1
			20·0	3	2·6
			20·0	2	4·1
			21·0	2	3·5
			14·0	5	3·2
			18·0	5	3·2
			20·2	5	4·7
			20·8	5	4·4
			21·2	5	3·7
			22·0	5	3·3

TABLE B. *Rolled Oats*

Normal temperature

Males			*Females*		
Weight (g.)	*No. of observations*	*Mean consumption (g.)*	*Weight (g.)*	*No. of observations*	*Mean consumption (g.)*
15·5	2	4·0	11·5	2	3·6
16·0	2	3·8	10·5	9	3·0
19·5	5	2·4	10·5	2	2·6
18·6	2	3·3	12·8	2	3·8
14·0	2	3·8	15·0	2	2·9
17·0	2	3·9	16·0	9	3·2
17·5	2	3·9	16·5	9	3·9
18·0	2	4·0	16·0	2	2·5
14·5	12	3·6	16·5	2	5·1
12·0	2	2·1	17·0	5	3·4
20·0	2	4·9	18·0	2	4·1
19·0	3	4·2	19·0	7	3·1
			18·1	2	3·4
			17·5	5	2·6
			21·0	2	4·1
			20·0	7	2·8
			20·5	5	2·7
			11·5	2	3·6
			16·5	2	3·0
			18·0	2	3·4
			18·0	2	2·5
			19·0	2	4·4
			19·0	2	3·6
			14·2	19	3·5
			11·5	5	4·2
			22·0	3	3·9
			22·0	3	3·8
			27·0	3	4·8
			14·5	3	3·6
			23·0	3	4·2

TABLE C. *Rolled oats*

High temperature

Males			*Females*		
Weight (g.)	*No. of observations*	*Mean consumption (g.)*	*Weight (g.)*	*No. of observations*	*Mean consumption (g.)*
14·5	2	3·5	20·5	7	2·8
17·5	2	2·8	21·0	7	2·6
18·0	2	2·2	22·5	7	2·7
13·8	24	3·0	14·0	4	2·0
			15·0	4	1·5
			19·0	4	1·8
			20·0	4	2·6
			21·0	4	2·3
			22·5	4	2·6

TABLE D. *Whole wheat*

Males			*Females*		
Weight (g.)	*No. of observations*	*Mean consumption (g.)*	*Weight (g.)*	*No. of observations*	*Mean consumption (g.)*
16·0	12	3·3	11·5	12	2·6
19·5	6	3·1	19·0	6	2·8
20·5	12	4·2	20·0	6	3·5
			19·0	2	3·8
			25·0	2	4·4
			15·0	2	2·9

4

METHODS OF CONTROL OTHER THAN POISONING

1. COMBINATION OF DIFFERENT METHODS

ALTHOUGH the main line of this research was poisoning, this does not mean that other methods are unsatisfactory, nor that a campaign should not employ a well-chosen mixture of all methods. Each house mouse infestation should constitute a separate problem, and a sequence of different methods, varying in order according to the particular problem, can often be profitably used.

For instance, in fairly large premises a general moving around and rearrangement of cover, if practicable, would usefully prepare the way for a campaign of trapping; it would however be a mistake to do this before poisoning because it would be difficult to trace the runways until the mice had settled down again. In very small premises disturbance might be an immediate advantage to the owner, but a distinct disadvantage to neighbours; ultimately, unless the campaign was carried out over blocks of premises, the disadvantage would come home to the owner through reinvasion. If food can be completely removed, this should be done before poisoning, and as a method of maintenance after successful poisoning a good mousing cat may be effective if cover is not too dense. Similarly, when a large stock of food is removed, e.g. from a buffer depot, the mice here should be exterminated before the next stock of food arrives. This is usually easy to do because the mice are hungry and bewildered.

We cannot too strongly emphasize that in urban premises very complete searching is necessary, and this should continue throughout the campaign, especially if traps or poison are apparently failing to clear the population. A M.O.F. official from the Midlands reported an instance in which trapping in a cold store was producing persistent and quite high catches; he made a further search and discovered that a pile of sheets of cork was completely riddled with runways of mice and when this was removed and the mice inside killed the rate of trap catches dropped suddenly. Broadcast baiting (to be discussed in later chapters) saves a vast amount of time which must otherwise be spent in making a complete search, but it cannot replace it entirely.

2. EXCLUSION OF MICE

As with rats, if methods of exclusion were universally practised, there would be no need for campaigns. However, apart from the fact that mice are more difficult to exclude than rats it is often impracticable or too

expensive to set up efficient barriers. Furthermore the maintenance of barriers is subject to the usual growing neglect, once mice have become scarce: nothing will persuade people that time spent in dealing with non-existent rats and mice is not time wasted and their attitude is very understandable. Thus barriers fall into disrepair, or, if erected at intervals round temporary habitats, are put up perfunctorily, with the result that eventually mice reappear and are well established before there is time to do anything about it.

In urban areas the setting up of barriers will most frequently take the form of proofing premises, when they have been cleared. There is nothing at all to be said for the prevalent and lazy method of filling up mouse holes with a twist of paper or nailing a slat of wood over them; zinc or tin are better as excluders and plaster with broken glass in it is best of all, but none of these is more than a temporary expedient. A great deal of time and trouble is often expended on putting up wire-netting barriers to prevent mice getting in and it is as well to make clear at once that no wire netting on the market will exclude all mice; little ones (6–8 g. in weight) constantly escaped from the Bureau's stock cages, which were covered with half-inch mesh wire-netting, and these are as capable of starting an infestation as larger mice. The only efficient way to exclude mice is either to use two layers of netting closely fastened together and with the meshes staggered, or to use wire gauze or perforated zinc. Even so, the latter will be gnawed through in time if it is not heavy and solid.

Nevertheless, if barriers on a large scale are inefficient, those on a small scale are not. Shutting up all food in tins or bins is a wise procedure, especially if they are inspected regularly to make sure they do not become battered and the tops ill-fitting. Wooden containers are not so good for obvious reasons, but judgement must be exercised: in a building where house mice are few and scattered, less efficient containers will serve than where they are abundant and have plenty of time and opportunity for undisturbed gnawing.

Finally, it is possible that substances will be found that act as efficient deterrents to mice. The Bureau has purposely not tackled this problem, apart from an early experiment by Elton using naphthalene to protect botanical type specimens, which were being damaged. In this instance a heavy concentration effected local protection, but would have been very expensive to use on any but the smallest scale. In any case this substance could not be used to protect food. These drawbacks—objectionable smell and limited range of action—probably apply to most of the deterrents that are recommended against mice. Nevertheless there is a fruitful field for research on these lines.

On farms the most obvious use of barriers is for ricks. Staddles were once widely used, but they are inefficient; in addition there is always the danger that mice may be carried from the fields into the ricks, when they

are being built. Efficient methods of surrounding ricks and other stacks of foodstuffs are expensive. Winterbottom (1922) reports that in the great Australian mouse plagues it was found that a perpendicular barrier of galvanized metal 18–24 in. in height would successfully exclude mice from piles of grain, and this observation is confirmed by some rough tests of the heights at which rats and mice can reach bait by a clear jump. About 10 in. was the limit for mice. The expense of such barriers would only be justified where very heavy damage is threatened and they would hardly be practicable on a farm, for they would quickly be knocked down or deformed, or, at any rate, weathered enough to provide a rough surface, which mice could scale. Venables found that barriers of uralite round ricks were quite impracticable.

There remains the possibility of treating the ricks in some way. The custom in certain parts of the country of including layers of sand, when the ricks are being built, is a very old one (see Worlidge, 1694), though not much used at the present day. This again seems worthy of proper investigation, though it must be a laborious business which few farmers would trouble to undertake. The only experiment carried out by the Bureau on the possibilities of deterrents for ricks was the dressing of one, shortly after it had been built, with creosote, but it contained as many mice at threshing as a control rick nearby.

3. MANIPULATION OF THE ENVIRONMENT

In town infestations the importance of periodic destruction or rearrangement of cover has already been emphasized. In house infestations the removal of all food is a comparatively simple matter in theory provided that the unusual types are not forgotten (e.g. soap and candles, see Ch. 3). In practice this is often neglected, so that a promising start in dealing with any infestation is to attend to this matter. Not only are mice then far easier to clear out, but they are unlikely to re-establish themselves if food remains inaccessible.

In shops and stores it is impossible never to spill anything. Matters may mend, when retail premises have no longer to keep large stocks and struggle with deficiencies of labour, but in any circumstances some routine inspection seems desirable, to check the worst kinds of carelessness.

On farms there is only one major way in which the environment can be manipulated, and that is by threshing early and providing mouse-proof stores for the threshed grain. Methods of storing in bulk, which have been developed in the last few decades and encouraged during the war by the M.O.F., are helpful against mice, but vulnerable to insect pests.

4. DIRECT KILLING

This method can only be catastrophic when it is possible to break down a large habitat containing many mice, a condition that may be found in

buffer depots and cold stores. Since it may often be impracticable to hold the store empty long enough to clear out the residual mice it is urgent that the greatest possible number should be killed while the goods are being broken down and removed. This presents some difficulties in a cold store, but in a buffer depot it is easy to arrange that the stacks are surrounded by an adequate barrier to prevent the mice escaping. In the case of a store of sacked oats that had been badly damaged by mice in an Oxford buffer depot, a barrier of shrimp netting about $2\frac{1}{2}$ ft. high was erected round the 500-odd sacks that were to be removed. Mice could, of course, climb over this, but usually they were so bewildered that they hesitated for some time at the barrier and could be killed fairly easily. The total killed was 117, and only about twenty mice escaped.

The same principle applies to ricks at threshing, though it is useless to leave the killing to the threshing gang, since they have neither the time nor the interest to interrupt their work every time a mouse bolts from the rick. During the Bureau's research upon farm infestations, we were often present throughout the threshing of a rick and we found it fairly easy to kill most of the population if there was an adequate barrier of shrimp netting. The job became even easier if the local schoolchildren were rallied to help. The details of the methods used are described in Chapter 13.

Venables carried out an experiment on a fairly isolated group of six corn-ricks. He was present throughout threshing and took care to kill every possible mouse, the total from the six ricks being 504 active mice and 139 nestlings. Two years later the effect of this extermination was still marked, the seven ricks threshed on this site containing only 'a few' mice.

5. PREDATORS

Natural predators of house mice in country districts are many, though it is doubtful whether in Great Britain and parts of north-western Europe, where their density has been spectacularly reduced by various factors, pre-eminently by game-preserving, they are ever numerous enough to act as a real brake on mouse populations.

Hawks, owls, and carnivorous mammals are the main predators concerned and in some parts of the world they must do a lot of good. Kalabukhov and Raevskii (1933) quote figures showing the reduction of mice (mostly *M. musculus*) in straw stacks due mainly to predators. Censuses on 30 December showed a density of 70–80 mice per cubic metre and by 10 January this had declined to 30–40; by 20 January this had been further reduced to about 2, a figure which thenceforward remained steady. This was presumably because the population had declined to a point where predators could no longer catch enough of them.

In western Europe at the moment we need not bother to consider birds and beasts of prey as serious agents of mouse mortality. However, this is not to say that hawks and owls do not at times (e.g. when a rick has been

threshed and a multitude of homeless mice are turned out into the hedgerows) perform a useful function, nor that they should not be encouraged in every possible way to increase as much as they can. The most important species concerned are the kestrel, *Falco tinnunculus*, and the barn owl, *Tyto alba*, in arable areas, and in the wilder parts the buzzard, *Buteo buteo*, and the short-eared owl, *Asio flammeus*, no doubt help to a certain extent. Strict protection of all these species could not but help in keeping down the numbers of field-living mice. Uttendörfer (1939) gives many figures from the analysis of castings taken from nests in Germany. These vary a great deal according to the locality and are biased because most of his material was collected during vole plagues. However, for the barn owl he quotes three cases, one in which 50 out of 85 prey were house mice, another with 92 out of 161, and a third with 592 out of 789. Evans (1947) analysed castings from a barn owl over 13 months in California and found 38% of prey were house mice.

Of wild mammals the weasel, *Mustela nivalis*, is about the only species in Great Britain that preys to a large extent on mice and its numbers are drastically reduced by game preservation and rabbit trapping. It is also one of the few predators that is small enough to enter a rick and follow mice into their own fastnesses, though the few instances in which weasels' nests have been found in ricks at threshing have not been notable for the dearth of mice. There is no doubt, however, that this species should be strictly protected.

Instances have been reported from various parts of the world of other rodents preying upon mice, sometimes with considerable effect. Thus Finlayson (1939) mentions that in Australia *Rattus villosissimus* preys to some extent on house mice: in both Malaya (Dammerman, 1939) and the Faeroes (Landt, 1810) authors state that house mice are scarce where there are populations of *R. rattus* and quite a number of cases are reported of *R. norvegicus* eating mice in some numbers. Gordon (1884) gives an instance of a rat's nest found in a rick in Scotland, in which were the remains of over a dozen house mice all with the skins neatly pulled inside out. Similarly Kalabukhov and Raevskii (1933) discovered a nest with no less than forty-one house mouse remains. During the Bureau's research we found mouse corpses in several ricks, skinned in the way mentioned by Gordon, and these were undoubtedly the work of rats. However, since most of these ricks had been poisoned, it is possible that the rats merely ate the bodies that they found already dead. All these instances refer to country districts. We also noticed one instance in which rats living in a M.O.F. buffer depot had been eating mice. A nest with seven small young was discovered in the middle of a stack of about 500 oat sacks and round the edge of the nest were twelve house mouse corpses, seven of which had been recently killed.

In Great Britain the fact that the brown rat preys upon mice is of no

great significance economically; one species is as bad as the other. It is a fact worth noting, however, when we consider the great efforts that are being made to reduce or exterminate populations of rats. If we do not also make war upon mice, any reduction in rats may lose much of its benefit, especially in ricks, by stimulating the mice to increase.

The domestic cat has long been accepted, perhaps rather uncritically, as the main stand-by in keeping down house mice. No particular work has been done on this problem by the Bureau, but observations have made it quite clear that large numbers of mice can survive successfully in spite of cats.

An investigation by Elton upon the effectiveness of cats in keeping farm premises clear of rats, suggests that, although cats cannot deal with an established infestation nor with rick populations some distance from the farm buildings, they can be used with advantage to maintain a clearance in farm buildings that has been made by other methods. It is therefore possible that the mere presence of a cat may help to deter recolonization. Although house mice present a rather different problem to rats, since a smaller range and more minute cover satisfies them, time to establish themselves in a new environment is still important (see Ch. 2), and it is at this point that they may be vulnerable to a cat.

6. TRAPS OTHER THAN BREAK-BACKS

Very little work has been done by the Bureau on catching mice except with the customary type of break-back trap, but we may briefly mention two methods.

(*a*) *Live traps.* There is little point in using individual live traps (of the box variety like the Tring or the Gamage) for catching mice, unless the mice are wanted for some special purpose. They are definitely less efficient than break-backs, and it is troublesome to deal with the mice caught. There is, however, a new trap designed by the Bureau and marketed by the Longworth Co. which needs no personal skill to set (and less discomfort than break-backs), and this advantage may counterbalance having to kill the catch.

Cumulative live-traps, in which a bait box is provided with a one-way entrance, so that mice can enter but cannot leave it, are said to collect large numbers, but the only two types tested by us caught no mice at all. One was a small box measuring about 6 in. all ways with a tunnel entrance leading down from the top. This type, although baited and placed in a heavily mouse-infested part of the Oxford market for about a fortnight, caught nothing. The same applied to a larger version about $18 \times 12 \times 12$ in., which had a number of tapering tubular entrances; this failed, although a female mouse was included in the trap when it was set.

One reason why cumulative traps for house mice fail is probably because mice have such a restricted range.

(*b*) *Sticky-boards.* In places where food is plentiful and mice are difficult to bait, boards with an adhesive preparation smeared on them will frequently catch large numbers of mice if sufficient are put down. In the last resort this method may be used, though it has disadvantages: it is not very cheap; it is probably inhumane; it may catch human beings; and the disposal of the mice after they are caught cannot be done neatly.

7. BREAK-BACK TRAPS

When all things are considered, break-back traps still remain the most economical and efficient way of clearing out small infestations of house mice, and during the early years of the war the Bureau continued to recommend that these traps should be used even on the large scale required in food stores. However, in such places a reasonable measure of success demands so many traps that the setting of them and the daily attention needed are expensive; furthermore they are tedious tasks in which people quickly lose interest. Recommendations for various methods of poisoning and gassing have now been made to replace the use of traps in all large infestations and in many of the smaller ones. This saves much time so that the available labour can be spread over a larger area and can attempt something more like 'block' control.

Break-back traps can be classified roughly as follows: (1) the type in which the trigger consists of a small tongue of wood or a wire prong. In this type the mouse has to step on to the platform of the trap and pull at or nibble the bait which is placed on the trigger. (2) The type in which the trigger forms all or nearly all of the platform of the trap, so that the mouse has only to step on to the trap in its effort to reach the bait to release the spring. Both types catch many mice, but on balance type (2) is the more efficient because it goes off when a mouse runs over it without any particular attempt to reach the food.

A break-back trap campaign can easily be ruined by setting the traps inefficiently. The main points to attend to are the following: the platform or trigger should move smoothly and freely (some makes require whittling with a sharp knife); the length of the arm which holds the spring or the position of the wire loop beneath which the arm is caught should be carefully adjusted so that the trigger or platform is only slightly up-tilted; all the operating parts should be kept free from rust and the trap dried out if it becomes wet; when the trap has been set as finely as possible, it should be placed down upon the ground very gently.

The traditional bait for a mouse-trap is, of course, a piece of cheese. In fact, mice eat cheese only rarely when they have a choice of food and the method of having the bait fixed firmly to the trigger is not the most efficient. Thus the type of trap which has only a wire prong on which to fix the bait is not always the best.

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An observation made by Venables provides evidence on the inefficiency of the 'fixed' bait. He watched three mice feeding at traps, which were baited with a small piece of cheese fixed to the trigger: two attacked the bait with a downward-gnawing motion and were caught straight away; a third, however, ate the bait with an upward-gnawing motion, which wedged the trigger firmly on to the arm holding down the spring. This mouse cleared two traps of cheese, but was caught at the third trap by changing its method of feeding. Thus it is obviously better to use a bait, such as rolled oats or flour, which can be sprinkled on the trigger or platform. If the trigger is touched during feeding it must be a downward motion, which should set off the trap. Of course, if the trap has a platform upon which the mouse must step before it can reach the bait, this consideration does not apply and the use of sprinkled bait becomes more a convenience than a part of the tactics of trapping.

Some people question the necessity of baiting traps at all. We have no figures for the comparative efficiency of the platform type of trap with and without baits. If these traps are set at right angles to a wall (see below), so that many of the mice are caught following their runway along the wall and so over the end of the trap platform, these mice will not be affected by the presence or absence of bait. To the other mice which are caught by being attracted to the bait, the comparative results with the trigger-type trap will be equally applicable.

Elton carried out a test in a 2-day 'trap-out' using 102 trigger-type traps. alternate ones of which only were baited (with rolled oats sprinkled on the trigger). The results were as follows:

	Room 1	*Room 2*	*Room 3*	*Room 4*	*Room 5*	*Total*
Baited . .	5	2	0	15	7	29
Unbaited .	1	1	0	11	1	14

These totals show that the baited traps were just about twice as efficient as the unbaited ones.

Just as important as knowing how to set and bait traps is knowing where to place them. Almost always mice will follow runways close to walls or any other objects in their habitat. Therefore to set traps lengthways against a wall is to risk missing all the mice which approach from the end away from the platform. If the trap is set at right angles to the wall with the platform towards it, they are equally liable to run over it from whichever direction they approach. Thus in all trapping campaigns carried out by members of the Bureau we have set traps in this way at right angles to the presumed course of the mice. Most makes of trap now bear instructions printed on them to this effect, but in so small a space these instructions are often condensed into unintelligibility.

Most trapping campaigns err on the side of using too few traps. Two

examples will make clear the scale on which traps were employed by the Bureau.

The first locality was a large drapery store in Oxford, consisting of two large floors of showrooms, in which the mice were concentrated mainly behind cupboards and serving counters, and about four smaller empty rooms at the back of the house. Baiting with small piles of rolled oats showed that between twelve and twenty mice were running about over most of the premises except in the showrooms where they were concentrated as mentioned. In all sixty-three traps were used to clear this infestation and they were only left down for 2 nights: a total of fifteen mice was caught.

The second locality dealt with by Elton provided the figures for comparison of baited and unbaited traps given on page 52. Three of the rooms contained stores of a grocery business and a fourth of a leather goods and bird-food shop. All rooms were small, but had abundant cover piled on shelves and on the floor in the middle of the room. In all 102 traps were used; twenty-seven mice were caught on the first day and sixteen on the second.

Thus anything from ten to forty traps might be placed in a single room. This number may be somewhat excessive, but it indicates that two or three traps only are next to useless where mice are at all numerous. A density of one trap for every 2 or 3 feet is by no means too great, especially where there are clearly defined runways. With the smaller mice we not uncommonly found that two traps had been cleared of bait, while a third had made the catch.

Notice that neither of the examples given above was carried on for more than 2 days. The policy should be to kill as many mice as possible quickly and not to keep the traps set for weeks, catching a dribble of the less wary ones, for this method sets a premium on astuteness in the mice by giving them as much experience as possible of how to avoid traps. Members of the Bureau carried out a large number of continuous trapping campaigns to secure samples of mice for investigating their reproductive condition (see Laurie, 1946). Table 7 shows the daily catches in some of these campaigns.

The figures for localities 2, 3, and 4 show the usual course of trapping a medium-sized infestation. Most of the mice are caught during the first 3 days, and all but occasional ones during the first 7 days. It is more efficient, therefore, to use large numbers of traps and to leave them down only for a short while. This gets rid of most of the mice and leaving down the traps for a longer time would have two undesirable results: (1) the labour expended in examining all the traps every day would be out of all proportion to the results, and (2) the remaining mice may become shy of traps and avoid them when another intensive campaign is carried out.

In localities 1 and 4*b* the continuation of catches was due to the difficulty

of working a large and varied environment. For efficient clearance probably more traps should have been used, and, if a week's trapping was not sufficient, it would have been better to leave a gap of a week or a fortnight between two trapping periods.

TABLE 7

	Locality 1 Restaurant	*Locality 2 Restaurant*	*Locality 3 House*	*Locality 4a Baker's*	*Locality 4b premises*
Number of traps:	*22*	*24*	*14*	*40*	*24*
Mice caught on day 1	15	7	5	5	6
,, ,, 2	..	7	4	13	2
,, ,, 3	18	10	4	3	4
,, ,, 4	6	3	..	2	2
,, ,, 5	3	2	2	2	3
,, ,, 6	4	1	..	..	..
,, ,, 7	4	2	0	3	5
,, ,, 8	2	1	0	0	2
,, ,, 9	..	..	..	1	1
,, ,, 10	5	1	0	3	4
,, ,, 11	4	0	0	..	2
,, ,, 12	5	0	..	..	1
,, ,, 13	4	0	..	..	..
,, ,, 14	1	..	0	1	1
,, ,, 15	..	1	..	..	0
,, ,, 16	..	..	..	..	1
,, ,, 17	6	..	..	..	3
,, ,, 18	5	..	..	..	1
,, ,, 19	1	..	..	..	0
,, ,, 20	2	..	..	..	..
,, ,, 21	1	..	..	..	5
,, ,, 22	1	..	..	..	3
,, ,, 23	..	..	..	..	3
,, ,, 24	2	..	..	..	..
,, ,, 25	1	..	..	..	1
,, ,, 26	2	..	..	..	0
,, ,, 27	3	..	..	..	..
,, ,, 28	4	..	..	..	0
,, ,, 29	2	..	..	..	..
,, ,, 30	..	..	..	..	0
,, ,, 31	3	..	..	..	..
,, ,, 32	0	..	..	..	..
,, ,, 33	1	..	..	..	0
,, ,, 34	..	..	..	..	..
,, ,, 35	..	..	..	..	..
,, ,, 36	0	..	..	..	0
Total	105	35	15	33	50
Per cent. caught days 1–3	31	68	82	64	24
Per cent. caught days 1–7	49	91	100	85	44

How uneconomic it is to leave traps down continuously is illustrated by figures supplied to the Bureau by Mr. C. H. B. Worrall of the M.O.F. He started an experiment in a large building of cold stores in the Midlands and

arranged that somebody should visit the twenty-four traps used 6 times a week. The trapping ran for a very long period, and the figures are only given from 28 July to 31 December. During this time the weekly catches were as follows: 5, 11, 6, 17, 5, 13, 10, 12, 11, 15, 4, 4, 8, 1, 23, 12, 5, 9, 3, 6, 0, 0.

Notice that these figures do not start with the initial setting of the traps and that they represent the tail of the trapping curve. This dribble of catches that went on for so long illustrates (*a*) the possible effect of trap shyness (periodic onslaughts with more traps would have been better), and (*b*) the waste of time incurred by using this method. Each of the figures given represents 168 trap nights, and, allowing on the average half an hour a day to collect the catch and reset the traps, a man would in this period spend 69 hours to obtain these rather meagre results.

TABLE 8

No. of traps	*Cold store A* 144	*Cold store B* 144
Mice caught on day 1	24	40
,, ,, 2	30	22
,, ,, 3	21	19
,, ,, 4	10	16
,, ,, 5	26	8
,, ,, 6	16	3
,, ,, 7	15	8
,, ,, 8	14	10
,, ,, 9	5	3
,, ,, 10	5	3
,, ,, 11	3	4
,, ,, 12	0	0
,, ,, 13	0	3
,, ,, 14	0	2
,, ,, 15	1	0
Total	170	141
Per cent. caught on days 1–3	44	57
Per cent. caught on days 1–7	83	82

Trapping in large stores and buffer depots, even with the best possible technique, is not very efficient, and in certain circumstances (e.g. stacks of bagged oats, where damage is bad and the grain is constantly trickling down on to the floor and wedging the platforms of the traps) can be very inefficient. Figures given later in this section to illustrate the effects of prebaiting and trap shyness show the rather poor results obtained in flour stacks even with the greatest care and trouble.

It is quite different when a store has been emptied of food. Naturally the mice are easy to trap and this method may be used if there is plenty of time before the next load of goods arrives. The figures (Table 8) obtained

for the M.O.F. by Mr. J. Carter of the P.L.H.A. show the typical quickly descending trapping curve and length of time needed to ensure a complete kill.

Break-back trapping is of course selective in that the smaller the mouse the less likely will it be to spring the trap. This means that there will usually be a few small mice just above the nestling size (mice leave the nest at about 5 g.) left behind to renew the infestation. In a small-scale trapping campaign in a flat in Oxford several adult mice were caught, but bait still vanished from the traps, although they were set as finely as possible. After two nights the remaining mouse was finally caught and its weight proved to be 6 g.

Figures for populations trapped in Oxford compared with samples caught by hand in ricks at threshing show how trapping misses the young mice.

TABLE 9

Weight in g.	*Trapped*	*Rick 1*	*Rick 2*
0·0—	0	11	13
2·5—	3	33	62
5·0—	15	25	34
7·5—	33	31	22
10·0—	41	48	34
12·5—	53	41	34
15·0—	52	48	53
17·5—	39	29	24
20·0+	34	5	2
Totals	270	271	278

It is doubtful how many mice below 5 g. would survive if their parents were trapped, but the deficit in the weight group between 5 and 7·5 g., which would all survive, shows the shortcomings of trapping.

8. TRAP SHYNESS AND TRAP PREBAITING

The fact that mice become shy of traps which have been left down for a long time is the main recommendation for trapping in discontinuous short bursts with large numbers of traps. Rzóska designed the following experiment to test the shyness of house mice towards traps.

In one end of a M.O.F. buffer depot were five large stacks of sacked oats fairly badly infested with mice. One of these he baited with small baits (*c.* 3 g.) of moist sausage-rusk, which were placed at regular intervals round the margin, both on the floor and on top of the first rank of sacks. Usually he renewed these every day. The test with the traps consisted in placing the bait at first upon unset traps and then setting the traps for one day, after which he unset the traps again. The amount of bait taken was recorded in two classes only: complete and partial take, and Table 10

shows the sequence of events up to the end of one phase of the experiment during which fifteen mice were caught.

TABLE 10. *Approach of mice to prebaited traps (unset and set). (Figures in brackets denote numbers of mice caught)*

	Oct. 16–18	*19*	*20*	*21*	*22*	*23*	*24–25*
	(baits only)	(unset traps and baits)		(traps set)	(unset traps and baits)	(traps set)	(unset traps and baits)
Complete take .	33	41	36	28 (7)	21	15 (8)	5
Partial take .	10	6	6	0	0	1	0
Total baits laid .	54	54	56	55	51	50	59

On 19 and 20 October the mice came to the unset traps readily and took the bait from them in a normal and unsuspicious way. The proportion of baits nibbled at and only partially taken was small. The first day's trapping killed seven mice, but it is noteworthy how many traps were cleared of bait without being sprung. This shows how difficult it is to ensure that all traps are efficient, however finely they may be set. On the day after the first trapping the mice were still fairly unsuspicious and still cleared a large number of the bait points. During the second trapping eight more mice were caught and they had still approached quite freely. After this, however, the take dropped considerably, and it was doubtful whether the number of mice caught could alone account for this.

Rzóska designed the next phase of the experiment to show more clearly what was the behaviour of the remaining mice. Accordingly each trap was surrounded by a patch of plaster of Paris to reveal footprints. In this way he recorded the number of traps that were approached, but not patronized. These are given in Table 11 as 'visits'.

TABLE 11

Approach of mice to bait points after trapping and to subsequent traps

	Oct. 26	*27*	*28*	*29*	*Nov. 1*	*2*	*3*	*4*	*5*	*6–7*
	(baits only)				(unset traps and baits)	(traps set)	(unset traps and baits)	(traps set)	(baits only)	
Complete take .	5	10	10	4	17	4 (3)	3	2 (2)	1	6
Partial take .	3	1	7	12	14	0	1	0	2	0
Visits . .	12	11	16	15	12	20	17	8	7	24
Total baits laid .	46	48	48	48	48	48	46	48	48	48

The figures from 26 October to 1 November (the day on which the traps were reinstated) show by the number of visits that the mice were approaching the baits nervously, and going away from many of them without eating, but during this period they gradually recovered confidence, since they took progressively more baits. However, there was a higher proportion of

partial takes than in Table 10, showing that the mice were still somewhat suspicious. The fact that there was actually a rise in the amount eaten on the day when traps were reintroduced (though unset) seems to indicate that the mice had temporarily overcome their nervousness of traps, but the small catch and large ratio of visits from 2 to 7 November indicate how quickly this shyness is resuscitated, and possibly that it is directed primarily to set traps. Thus there seems to be a gradation in degrees of shyness: set traps are the most frightening, unset traps come next, and plain baits last. The behaviour of the mice moves up and down this scale according to their immediate experience: after trapping they are even nervous of plain baits.

The poor catches in Table 11 compared with Table 10 cannot be attributed merely to the reduction of the mice in the stack. On 7 November there were still plenty of points being visited and it is undoubtedly the behaviour of the mice to the traps that is responsible.

An experiment on another stack was also interesting. Much the same procedure was followed as in the one discussed above, but the nervousness of traps was more prominent. The relevant results are given in Table 12.

TABLE 12. *Approach of mice to unset and set traps in oat stack 1*

	Oct. 18	*19*	*20*	*21*	*21–29*	*Nov. 2*	*3*
	(baits only)	(traps unset and baited)					(traps set)
Complete take .	31	6	10	25	25	20	2 (2)
Partial take . .	13	11	6	0	0	0	0
Total baits laid .	61	59	63	57	57	57	57

When unset traps were introduced on 19 October the amount of bait eaten fell sharply (this contrasts with events in Tables 10 and 11), but recovered during the course of 2 or 3 days, and stayed at the same level for over a week until the traps were set. This was an almost complete failure. The most probable explanation is that since this stack had been heavily trapped $2\frac{1}{2}$ months before during a previous experiment, the trap shyness induced then must have persisted right up to the present test. This result emphasizes how important it is to avoid producing trap shyness in house mouse populations.

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5

POISONS FOR HOUSE MICE

1. POISONS NOT TESTED BY THE BUREAU

THE number of poisons recommended for use against house mice is legion and it would be pointless to offer comment except upon the following three heads.

(*a*) '*Virus*'. None of these preparations has been tested in the field. Leslie (1942) has typed the main ones used and gives a discussion upon the possible dangers of using such organisms.

(*b*) *Strychnine*. Many authorities outside Great Britain (e.g. U.S.A.) recommend the use of strychnine for killing mice. In Britain its use is forbidden because of its very high toxicity.

(*c*) *Phosphorus baits* are sold widely for use against mice. We have not tested any of them at the Bureau since zinc phosphide is superior in many ways. It is perhaps worth noting that the typical symptoms produced by phosphorus poisoning suggest that it is probably one of the most painful that can be used.

2. POISONS UPON WHICH SMALL-SCALE TESTS HAVE BEEN MADE

Various substances have been suggested at one time and another as possible mouse poisons and quick tests were carried out on the most promising. The standard procedure was to place six wild mice from the Bureau's stocks in a cage measuring about 2 ft. × 1 ft. × 6 in. with two cover boxes in it. These mice were supplied with plain food and the amount eaten weighed every morning. When their consumption had reached a steady level, poisoned food was substituted for the plain, the mortality checked at intervals of 24 hours or less and the consumption of the poison bait noted. This procedure is referred to as a *group free-feeding test* and claims no more than to give a rough idea of the palatability of the poison, its toxicity, and the speed with which it works. Usually such a rough test was quite sufficient to decide whether or not to continue experimenting. Later tests were done upon batches of mice, with a separate cage for each individual, and these are referred to as *individual free-feeding tests*.

Table 13 summarizes the results obtained in this way. No comment is necessary on some of these, but on others the following information is worth noting.

(*a*) *Sodium silicofluoride*. We carried out a further test with this substance to discover its efficiency when scattered in the mouse's environment so as to cling to their fur or feet. Statements have been made that mice in cleaning themselves swallow sufficient of the poison to be killed. For this

purpose twelve mice were freed in an outdoor shed which contained plenty of cover but no food. Three jars with rolled oats in them were placed about the shed and, after the mice had become accustomed to feeding here, two of the jars were surrounded by a 2 in. wide band of silicofluoride so that the mice coming to feed there must needs tread on it. Each of the treated points showed a slight drop (15 g. to *c.* 10 g. and 15 g. to *c.* 8 g.) almost at once, but

TABLE 13. *Free-feeding tests on wild mice with various poisons*

Poison	*Type of test*	*Concentration and bait*	*Mortality*	*Poison take: last day prebait (g.)*	*Time of death*
Sodium silicofluoride	Group FFT	10% in rolled oats	4/6	3/14 = 21%	3 in < 24 hrs. 1 in < 56 hrs.
Tartar emetic	,,	10% in rolled oats and flour	1/6	3/19 = 15·8%	1 in < 48 hrs.
Barium arsenite	,,	10% in sausage-rusk (dry)	0/3	0·4/8·75 = 4·8%	..
Di-nitro-orthocresol	,,	4% in bread mash	0/2	8·2/20 = 43%	..
,,	,,	8% in bread mash	0/2	7·9/20 = 39·5%	..
,,	,,	16% in bread mash	0/2	5·6/15 = 37%	..
Cuprous cyanide	,,	10% in rolled oats	0/5	< 0·25/12 = 2·1%	..
,,	,,	15% in rolled oats	0/5	< 0·25/13 = < 1·9%	..
Zinc cyanide	Individ. FFT	3% in rolled oats	2/6	1·3/11·7 = 11·1%	1 in < 15½ hrs. 1 in < 40 hrs.
α-naphthylthiourea	Group FFT	1% in rolled oats	3/5	0·9/10·5 = 8·6%	2 in < 4 hrs. 1 in < 5½ hrs.
Barium carbonate	Individ. FFT	20% in rolled oats	7/10	4·5/36·5 = 12·3%	1 in < 24 hrs. 1 in < 48 hrs. 3 in < 72 hrs. 1 in < 120 hrs. 1 in < 288 hrs.

this trend did not continue. The untreated point remained at its previous level. Renewing the silicofluoride caused another drop which was not continued. In all, the daily amount of food taken was reduced during the experiment by about half. The experiment showed that a small number of mice was killed at each application, but the mortality did not continue, perhaps because the poison became too caked after the first night's trampling to adhere to the mice's feet. Since in the second treatment 60 g. of silicofluoride was used, it is clear that the attendant danger in spreading about so much poison far outweighs the meagre results.

(*b*) *α-naphthylthiourea* (Antu) is a highly toxic poison (about on a level

with strychnine), which was developed in America during the war. It is alleged to be practically tasteless, but this small-scale test showed that even white mice would not all take sufficient to kill them. A single field test was carried out in a grocer's shop in the Oxford market: the first treatment certainly killed a large number of mice (ten corpses were picked up), but the population made a quick recovery and a second treatment was mainly remarkable for killing two kittens that had been introduced. Since the toxicity of Antu is so high and there is no known antidote, we investigated it no further.

(*c*) *Barium carbonate.* This substance is fairly satisfactory as a rat poison, but often has to be avoided because it is highly toxic to cats. This experiment shows that even under the optimum conditions of a free-feeding test, where the mice have no alternative food and were given the poison in the evening, when their stomachs were empty, only 70% of them died. Thus barium carbonate seems to be even less efficient as a mouse poison than as a rat poison.

3. RED SQUILL

Since poison baiting for house mice necessitated broadcasting many small baits (see Ch. 8), and since residues of poison, particularly in places like food stores and ricks, are generally undesirable, the toxicity of red squill to mice was thoroughly investigated. The results were discouraging and in the end we abandoned this line. Since, however, a few field tests of red squill were moderately successful, and since in practical control work there are bound to be some localities where no poison but squill would be countenanced, it is worth giving the results of the Bureau's work in full.

The first experiment was a group free-feeding test upon three wild mice using red squill powder. The food used for this test was rolled oats with 20% olive oil added to it. After several days on this diet the take measured at 10.30 a.m. on the last day was 6·25 g.; the same base with 10% red squill powder was given to the mice at 3 p.m. after they had been without food for nearly 6 hours. By next morning they had eaten 1·3 g. of the mixture (20·8% of the prebait) and all were perfectly well. Plain food was given and by the next morning they had eaten a normal amount of it and continued to do so. Taking the average lethal dose of this batch of squill from rat figures, the mice (with due allowance for their weight differences) had eaten some thirty-six average lethal doses without any ill effects at all.

This result seemed so remarkable that the experiment was repeated on a larger scale. The same routine was followed and in the first experiment three batches of mice, eleven in all (seven of which were females), were offered 20% red squill powder in oiled rolled oats. They ate an amount equivalent to 5·3% of the last day's prebait and none of them showed the slightest qualms, although each must have had about two average lethal doses. At the same time a further experiment was done upon six mice re-

peating the 10% concentration. In this instance they took 2·7% of the last day's prebait, and two (both females) died.

In these free-feeding tests only two mice died out of a total of twenty in spite of the fact that they had eaten many lethal doses calculated on a 'rat basis'.

We therefore abandoned tests with powder and turned our attention to extracts. Details of the way in which alcohol extract of red squill is prepared are given elsewhere (see Vol. 1, Ch. 2). The water extract used in these experiments was made by simply adding water just off the boil to the powder, leaving the resultant 'porridge' to cool and then pressing it through a fairly fine cloth. In either case we rated the extract by its equivalence to powder, so that when using the term '1% extract' it should be understood that the bait indicated contained as much squill as could be extracted from the amount of powder that would make a 1% mixture.

Since both the extracts are kept in liquid form we used a moist bait throughout the experiments. Sausage-rusk was the best for this and could be made up simply by adding extract suitably diluted to the dry rusk and mixing it up. We estimated the amount of plain and poison bait taken by drying the residues in the way explained in Chapter 3. We then carried out a long series of experiments in which each mouse was kept in a separate cage with a cover box but without chaff or hay; thus the spilled food could be collected up more easily from the floor of the cage each morning before being dried and weighed. This arrangement may have increased slightly the amount of food taken by each mouse owing to lack of insulation. However, this would only happen in very cold weather (see Ch. 3).

The main experiments were done with water extract at 1% and alcohol extract at 1 and 5%. Since we soon perceived that the margin of toleration (before the amount of extract made the bait unpalatable) was somewhere around 5%, a further experiment was done with water extract at 2·5%. In all experiments the sexes were kept separate, so that we could determine whether the females were more susceptible. Furthermore, parallel experiments were done with plain sausage-rusk and with sausage-rusk to which 10% castor sugar had been added to see whether this masked the taste of the squill. A final experiment compared two batches of water extract, one of which contained 0·18% salicylic acid. This was to find out whether the addition of a fungicide to the extract would alter its palatability. Water extract keeps for only a short time without the addition of some such preservative as this.

The results of these experiments are presented in Table 14.

These results were extremely promising, since at the lower concentrations not a single mouse out of the large series tested survived, and all the casualties except two died in under 24 hours. The take of poison bait expressed as a percentage of the last day's prebait is constantly large, and, if we adopt the level of toxicity established for the brown rat, then in

proportion each mouse took on the average about two lethal doses of squill.

TABLE 14. *Results of free-feeding tests with squill extracts on mice*

Extract used	*Mortality*	*Rate of dying*	*Take of poison bait % last day's prebait*
Alcohol extract 1% .	6/6	5/6 in 24 hrs.	12·6% (6 records)
,, 5% .	7/12	5/7 ,,	Not measurable
Water extract 1% .	45/45	1/45 in 5 hrs. 44/45 in 24 hrs.	11·5% (39 records)
,, 2·5% .	6/6	6/6 in 24 hrs.	11·3% (6 records)

At the higher concentration it is clear that the poison bait is becoming unpalatable. The mice tested did not all die and the amounts of bait eaten were too small to weigh.

These experiments also showed that the addition of 10% sugar to the bait did not increase the amount taken, which presumably means that the plain bait was sufficiently palatable for the mice to go on eating until warning symptoms developed. They also showed that the addition of 0·18% salicylic acid made no difference to the take, and therefore that the keeping qualities of water extract can be extended from a few days to as many weeks.

The analysis of sex differences showed that the mortality fell equally on males and females and that there was no difference in the time taken to die. In the case of poison bait take, however, there was a constant small difference, males always taking more than females. From twenty-one observations the mean ratio of poison take to prebait take for males was 12·5%: for females (nineteen observations) 10·5. Here, presumably, is evidence of differential susceptibility between the sexes to squill poisoning, a difference which had been amply demonstrated for rats.

Unfortunately field experiments did not confirm this promise. The failure was most marked in the habitat, where above all others squill would have been invaluable, namely, in corn-ricks. The experiments upon poisoning corn-ricks are given in detail in Chapter 13, and these show, among other things, that it is almost impossible to exclude the possibility of small amounts of poison bait residue coming through into the corn at threshing, especially if moist sausage-rusk bait is being used. If only squill extract could be used this would not matter, but the results in Chapter 13 show clearly that it kills only a few mice.

Another habitat, in which squill would help, is the large food store. In large stacks of sacked flour or grain many mice admittedly visit the margins (see Ch. 2), but it is impossible to reach those living right in the middle except by dropping baits down from the top of the stack between the interstices of the sacks. If this is done, of course the poison residues cannot be recovered, and may get mixed with the sweepings after the stack has been removed. These sweepings generally go for pig or poultry food. Field ex-

periments with squill show that moderate results can be obtained, but the outcome is uncertain and variation between 50–60% kills and complete failures have been obtained.

In a M.O.F. buffer depot near Oxford two adjacent stacks of sacked oats measuring each 37×32 ft. and about 8 ft. in height were selected for treatment. Small cylinders of moist sausage-rusk, each weighing about 2–3 g., were placed round the margins of each stack, and the total was increased until it was certain that the maximum number of baits were being taken. In one stack the mean number of baits taken per day during 6 days' prebaiting was about forty, in the other about seventy. Next, poisoning was done with 1% (powder equivalent) water extract of red squill, each stack having 100 baits placed round the margins and sixty-six further ones dropped down inside from the top. Seven days' postbaiting showed an average take in the first stack of about twenty baits and in the second stack of about thirty-five baits. Probably each of these populations was reduced by about 50%. This is an unsatisfactory result, but squill may be worth using if no better method is available.

On the other hand, in some stacks that were treated in a similar way we found no perceptible drop in the amount of plain bait taken after the poisoning. These failures may not be entirely attributable to the use of squill, since the same kind of results could just as well be obtained in this environment with arsenic or zinc phosphide.

In the more frequent types of urban habitat only a few experiments were carried out with squill, since in most cases it is possible to recover all the poison residues. If this is so, other poisons can equally well be used. However, at times squill may be valuable. The Oxford market, which is a large area containing a heterogeneous collection of shops, many of them very untidy and cramped, is an example where the use of squill lightens the labour of collecting up the uneaten baits, since it is of no great concern if a few are overlooked. This experiment is described in detail in Chapter 11 and here it is only necessary to indicate that, judging from the postbait eaten, something under 50% of the mice had been killed. A remarkable thing about the results was the wide range of kills in different premises (0–95%), which confirms the unpredictability of squill as a poison.

These results show that there is little room for improvement in the actual processing and production of squill baits; results could hardly be better than the ones obtained in laboratory tests. The obstacles to the success of squill are entirely due to conditions in the field and in spite of much work it has not been possible to resolve these difficulties. Squill remains a poison only to be used as a last resort in places where poison residues are difficult to collect, and where a chancy success is better than none at all.

Finally, we give the data obtained by Rzóska during a small-scale experiment to discover the hesitation and refusal times for squill poisoning. The technique of these experiments was standardized and is described in

connexion with similar work upon rats (see Vol. 2, Ch. 8). His method here was to give small pills of bread paste containing about 1·5% of water extract of squill (powder equivalent) to tame mice accustomed to feed from the hand. The mice had previously been partially starved, i.e. they had only been given a small amount (3–4 g.) of bread paste to eat during the previous night. The bread paste contained about 15% by weight of water, to which the extract was added, and small pills of 0·25 g. were offered to each mouse every 5 minutes from the start of the experiment. After the first 20 minutes the amounts were reduced to 0·125 g. Rzóska had previously determined that the mice would eat at this speed by offering them plain bread paste pills in exactly the same way. The results of this experiment are given in Table 15. The four mice used were female piebalds, all of about the same weight (23–26 g.).

TABLE 15. *Times of hesitation and refusal in taking offered squill baits*

No.	*Hesitation signs (min.)*	*Refusal (min.)*	*Total of bait eaten*	*Contained extract*	*Illness (min.)*	*Death*
1	65, 80, - - -	90 - - -	2·7 g.	40·5 mg.	80	22 hrs.
2	75 - - -	95 - - -	3·1 g.	46·5 mg.	80	,,
3	65, 80, - - -	85 - - -	2·7 g.	40·5 mg.	Nil in 100 min.	27 hrs.
4	65 - - -	80 - - -	2·6 g.	39 mg.	95	As 1 and 2

From the table we see that these mice took the small pills of bait readily every 5 minutes and the first signs of hesitation in accepting the bait did not occur until just over 1 hour after the start of the experiment. Complete refusal followed in 10 to 20 minutes, sometimes coinciding with the appearance of actual signs of illness. These results show that squill is fairly slow in its action upon mice, and that for about an hour after eating the first bait they will take more quite unsuspiciously. During this time they will readily eat what would be considered a large number of lethal doses, if we assume a toxicity rate in mg. per kilo at the same level as that for rats.

4. ARSENIOUS OXIDE

Reactions of house mice to this poison are similar to those of brown rats, and readers may refer to details of toxicity tests upon rats which consider among other factors the variation according to the fineness of the powder used (see Vol. 1, Ch. 2).

Preliminary group free-feeding tests were done upon house mice with various grades of arsenious oxide at various concentrations, and, since they give rough figures which can be compared with similarly obtained results for other poisons, they are summarized in Table 16.

From these results we cannot say that any of the grades used is the best.

With each type and each concentration some mice survived, and in large-scale field experiments such survivors will constitute a difficult problem, especially as the percentage of them under field conditions may be greater than in the laboratory. Most of them will be shy of bait and therefore more difficult to treat a second time. In a small-scale experiment upon some free-living mice in a cellar at Oxford, prebaiting and poisoning was carried out in the usual way and the numbers (6–8 mice) reduced. Break-back traps were then put down and two mice were caught, one of which had traces of arsenic in the intestines. This survivor must have eaten a sublethal dose of the poison and would probably have refused further poison baits.

TABLE 16. *Group free-feeding tests upon wild mice with different grades of arsenious oxide*

Grade used	*Concentration*	*Base*	*Mortality*	*Ratio poison: prebait take*
	%			%
Harrington's fine .	10	Rolled oats or wheatmeal	13/15	9·25 (2 observations)
,, .	15	,,	10/10	12·7 (3 ,,)
,, .	20	,,	8/9	6·3 (3 ,,)
Total . . .			31/34	
Refined Canadian .	15	,,	3/5	11·3 (2 ,,)
,, .	20	,,	7/8	15·2 (2 ,,)
Total . . .			10/13	
Russian . . .	15	,,	9/11	20·6 (3 ,,)
,, . . .	20	,,	6/6	5·9 (2 ,,)
Total . . .			15/17	
Total (all types)			56/64	

The results in Table 16 show that on the whole smaller quantities of poison bait were consumed when it was given at a concentration of 20%. This probably means that this amount of arsenic is beginning to be unpalatable to the mice. It is unlikely that the difference is due to smaller concentrations giving more time for symptoms to appear. Rzóska's more detailed work upon rats (see Vol. 2, Ch. 8) has shown that the time before hesitation and refusal varies little over quite a wide range of concentrations so long as the amounts eaten are above the average lethal dose.

The effect of arsenious oxide upon the behaviour of the mice is swifter than that of squill. An experiment upon three white mice by Rzóska, using the same technique as in the squill test (see Table 15) except that the food offered was sausage-rusk mash, is detailed in Table 17. The percentage of arsenic used was 10%, and each pill (offered every 5 minutes) weighed 0·125 g., thus containing 12·5 mg. of arsenic.

The idiosyncrasies of arsenious oxide as a poison bait for mice in the field

TABLE 17. *Times of hesitation and refusal in taking offered arsenic baits*

No.	*Weight and sex*	*Hesitation (min.)*	*Refusal (min.)*	*Total bait eaten*	*Contained arsenic*	*Time of death*
1	31 g. ♀	20	30	0·81 g.	81 mg.	under 24 hrs.
2	29·5 g. ♀	20	30	0·81 g.	81 mg.	,,
3	26·5 g. ♀	20	20	0·5 g.	50 mg.	,,

will not be dealt with in this chapter, since we consider them later, when field baiting problems are surveyed (see Chs. 8 and 9). We must, however, mention one point here. Arsenic often produces longer bait-shyness in mice than any other poison. Unless an experiment is carefully done, this fact may not be revealed, and it is possible to interpret a field trial result as nearly 100% successful, whereas in fact it may be almost a complete failure. An experiment carried out in flour stacks at a M.O.F. buffer depot illustrates this very clearly. Two stacks of about the same size were each baited with fifty baits (*c.* 2 g. each) of moist sausage-rusk, and three poisons, red squill extract, arsenious oxide, and zinc phosphide, were used in turn. The daily figures (Table 18) for the amount of bait taken show the peculiar effect of arsenic.

TABLE 18. *Daily take of baits in two flour stacks during treatments with squill, arsenious oxide, and zinc phosphide*

Day:	*12*	*13*	*14*	*15*	*16*	*17*	*19*	*20*	*21*	*22*	*23*	*24*	*26*	*27*	*28*
Stack 1	36	38	33	33	..	..	Squill	26	29	23	19	23	22	..	..
Stack 2	..	..	45	47	46	37	poisoning	38	45	39	41	46	26	32	46

Day:	*29*	*30*	*31*	*33*	*34*	*35*	*36*	*37*	*38*	*47*	*48*	*49*	*50*	*51*	*52*	*54*	*55*
Stack 1	Arsenic	0	1	21	24	33	33	37	34	45	40	..	..	Zinc phos-	14	37	37
Stack 2	poisoning	0	8	18	16	14	15	30	40	43	31	42	34	phide poisoning	31	43	36

All these poison trials were remarkably unsuccessful, but unless we had continued baiting it would have been very easy to infer an almost complete kill after arsenic. The fact that no bait at all was eaten on the first day after poisoning, then gradually increasing amounts (quicker in stack 1 than in stack 2) is probably due in part to illness after sublethal doses of poison. Nevertheless, other experiments prove that mice may disregard the bait for a day or so because of a generalized shyness and not because they are incapacitated through illness; in these tests plaster of Paris patches showed that the baits were being visited, even though none was eaten.

This phenomenon does not always occur after the use of arsenic, but it has been noted sufficiently often for it to be pointed out as a possible source of confusion.

5. ZINC PHOSPHIDE

This has been the poison most often and most successfully used against house mice. Preliminary group free-feeding tests gave the results shown in Table 19.

TABLE 19. *Group free-feeding tests on wild mice with zinc phosphide*

Concentration	*Base*	*Mortality*	*Ratio poison bait: prebait taken*
2%	Rolled oats	2/2	12·5% (1 experiment)
5%	,,	12/12	12·0% (2 experiments)
10%	,,	11/11	10·5% (2 ,,)

Rzóska also investigated hesitation and refusal times with zinc phosphide baits, in a way strictly comparable with the previous experiments on red squill and arsenious oxide. Bread paste (dry bread crumbs with 15% water) was used as a base for the poison and pills containing 10% of the poison were offered every 5 minutes to domestic mice, which he had accustomed to take food from the hand. The only difference between this and the other experiments was that he offered smaller quantities (0·0625 g. instead of 0·125 g.) each time, since zinc phosphide is more toxic than arsenic or squill. The concentration of 10% was used, since this was the strength used at the time in field trials. Results are shown in Table 20.

TABLE 20. *Times of hesitation and refusal in taking offered zinc phosphide baits*

No.	*Sex*	*Hesitation (min.)*	*Refusal (min.)*	*Total bait eaten*	*Contained z. phos.*	*Illness*	*Death*
1	♀	55	55	1·1 g.	110 mg.	72 min.	2 hrs. 40 min.
2	♀	65–70	80	1·3 g.	130 mg.	80–85 min.	3½–4¼ hrs.
4	♀	25	30	0·6 g.	60 mg.	140–5 min.	3½–4¼ hrs.

Mouse No. 3 which had not been properly accustomed to feed from the hand ate about five pills irregularly, became ill in 68 minutes and died between 3½ and 4¼ hours.

The results of this experiment are interesting. In the first place individual mice vary in the times of hesitation and refusal, but on the whole the effect of the poison upon behaviour is delayed compared with the arsenic results, and the figures fall roughly in between those for the latter poison and for red squill extract. The onset of symptoms is sudden and complete refusal to take any more of the bait follows almost at once or at the most within 10 minutes. Death occurs extremely quickly, though we must point out that each of these mice took a relatively enormous quantity of poison. If we use the average lethal dose for rats as a standard, mice should need only a

few milligrams to kill them, so that some 50–100 times this amount was eaten by mice Nos. 1 and 2.

From these results it seems probable that zinc phosphide will be the best poison to use in the field; warning symptoms do not appear so early as with arsenic and, therefore, there is time to eat a remarkably large quantity of bait. This is important, when we think of the sporadic and diffuse feeding habits of house mice in natural habitats.

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6

THE FEEDING ACTIVITY OF THE HOUSE MOUSE

1. INTRODUCTION

Our early failures to poison house mice intimated to us that any simple adaptation of methods used for the brown rat, *Rattus norvegicus*, was inadequate.

So, together with other investigations designed to throw light on the fundamental factors influencing the consumption of plain and poisoned baits by house mice, we started an experimental analysis of feeding activity. The first object of these experiments was to establish the basic feeding rhythm of mice, uninfluenced as far as possible by such factors as varying day-length, disturbance, and social and sexual drives. The second object was to test what change in feeding habits was caused by altering the position and kind of food offered.

2. PREVIOUS WORK

There is much literature on the activity rhythms of animals. Most of this has been summarized recently by Kalabukhov (1940). As far as rodents are concerned, most of the work concerns domesticated strains of rats and mice, but several papers have appeared upon wild species studied in captivity (e.g. *Apodemus* and *Microtus* spp.), and there is one study of wild house mice.

The methods of recording activity have differed: many of the American authors, studying white rats, have used a cage-wheel, taking the number of revolutions as an index to activity. This is rather an unnatural arrangement with no definite relation to feeding habits, so the results need wary interpretation. Most of the other work upon domesticated breeds of rats and mice has used a cage supported upon springs, any movement of which is communicated to a pen-lever writing upon a revolving drum. This method is more satisfactory, though it has the disadvantage that many movements unconnected with feeding—even those made in sleep—will be recorded.

Still better is the arrangement whereby the cage is divided into two compartments, one of which forms the nest box. Any movement into the outer part is recorded and the general picture is not distorted by small-scale movements which do not involve actually leaving the nest box. This method was used for all the experiments upon small mammals other than house mice, and has the advantage of simulating to some extent natural conditions.

Finally, there is the method of registering feeding activity only by means of a recorder attached to the feeding tray. There is probably no great

divergence in results between this and the last method because (as explained later) there is very little activity involving leaving a cover box and moving out into the open which does not include feeding as well.

In nearly all this work the main conclusions are that activity manifests a short-term periodicity (1–4 hrs.) related to the stomach capacity and a long-term one (generally 24 hrs.) related to the alternation of day and night. The general picture for any species is usually a composite one showing the influence of both periodicities, modified to meet ecological requirements in each case.

Of the work done upon white rats that of Richter (1927) demonstrates most clearly the short-term periodicity. Kymograph records of rats kept in cages without food showed that a bout of activity recurred with striking regularity every 1½–2 hours; when food was given the rhythm extended to 3–4 hours, and each period of activity followed a well-marked course in which the animals gradually grew more restless until they ate food and became quiet again.

It is curious that Richter's rats apparently showed no trace of day–night rhythm, but perhaps this may be suppressed in some domestic strains. However, it is difficult to judge because Richter does not say what were the conditions of temperature and lighting and what was the previous history of the stock used.

Work by Slonaker (1907) on the contrary shows a very emphatic 24-hour rhythm. The conditions of his experiments were not very satisfactory from the present point of view because activity was measured in revolutions of a cage-wheel, and food was supplied which the rats carried into their boxes. Thus day-time activity may have been artificially depressed and it is not clear what relation the nightly activity bore to feeding. The most interesting result was the unanimous start of activity just as dusk fell.

Further experiments upon white rats by Shirley (1928) and Szymanski (1918) are more illuminating. In both cases total activity, as distinct from feeding activity, was recorded. Szymanski found night activity well marked, being almost continuous from 4 p.m. to 4 a.m. with peaks in the evening and early morning. We shall discuss this diphasic nature of night activity later. Szymanski found that his rats had about ten active periods during each 24 hours. These may correspond with the short-term rhythm demonstrated by Richter, when food was not given, but it is difficult to be certain about this, since the amount of day-time feeding is not known.

Shirley kept rats in continuous light and found that the 24-hour rhythm was not entirely eliminated. Although the major peak of activity came in the morning just after the rats had fed, there was still a minor peak at the time when dusk would normally have fallen.

Further analysis of the factors controlling the 24-hour rhythm has been made by Browman (1937, 1942, 1943). Activity was measured with a cage-wheel with disadvantages already mentioned. However, the method gives

a gross measure of the longer rhythm, though alterations in intensity will not necessarily mean changes in food consumption.

Under normal conditions activity was concentrated during the night. Reversal of the normal night and day produced a reversal of the daily distribution of activity. If kept in perpetual darkness the rats would maintain the rhythm shown before the experiment started. If kept in perpetual light the rats still preserved a 24-hour rhythm, but this was subject to reversals every 6–12 days, in which the incidence of activity would shift by 12 hours, just as if a reversal of day–night rhythm had been imposed.

The main conclusion from this evidence must be that a 24-hour rhythm of activity is as much a part of the rat's organization as is the shorter 2–4-hour rhythm: both these rhythms are labile and can be adjusted (often surprisingly simply) to factors in the physical environment. The result is a delicately balanced mechanism adjusted to normal ecological requirements but sufficiently plastic to vary with conditions.

Normally in nature the external rhythm to which that of activity is matched is the alternation of day and night. This matching is usually effected through change in light intensity, though Browman has further shown that if this is absent, change in temperature may take its place.

Observations and experiments carried out upon wild brown rats by Chitty and others (Vol. 1, Ch. 4) and by Chitty and Shorten (1946) show how this mechanism works under natural conditions. A wild population of rats was given food in excess of their requirements and the rate of consumption was measured automatically throughout every 24 hours. Under these conditions the feeding rhythm was very steady; the rats fed almost entirely at night-time and started with great regularity at dusk. When the food supply was kept below their requirements and the time of replenishment altered, it was possible to alter the feeding rhythm, and in one experiment considerable day-time feeding was induced. This shows that a normally adjusted feeding rhythm can be changed by the availability of food in spite of constant light and temperature rhythms.

These results of work upon rats establish the main picture of the feeding rhythm of rodents and its proximal causes. When we turn to work upon the smaller species we find that they differ considerably according to their ecological status, but the main pattern still holds.

Davis (1933) shows very clearly with *Microtus agrestis* the effect of the long and short rhythms combined. This species is vegetarian and eats a large bulk of food in proportion to its weight. Therefore feeding continues through most of the 24 hours at intervals of about $2\frac{1}{2}$ hours, but there is an intensification at sunset, which continues strongly until midnight and somewhat less strongly until dawn. From the figure given by Davis we can see that during the day each burst of activity lasts about 20–50 minutes and is followed by some 100 minutes' rest: at sunset the relation between these two quantities is approximately reversed. This occurs quite suddenly, but

the change back to the day relation is much slower: from midnight onwards the periods of activity become gradually shorter and the periods of rest longer, so that by about 8 a.m. the original relation is re-established.

Thus the 24-hour rhythm is imposed upon the shorter one; but this is not to say that it is in any way secondary nor that its limits and intensity cannot of themselves be objects of selection. The work upon rats has shown that this rhythm can be adapted to experimental conditions, and investigation of wild specimens of the smaller species suggests that they are adapted to their natural conditions.

Various species of the genera *Peromyscus* and *Apodemus* have been investigated, and, since all are nocturnal, we may discuss the group together. All the workers except Johnson recorded activity by the frequency of visits to an outside cage from a nest box. Most of the activity curves or histograms published exhibit a very marked 24-hour rhythm, closely in step with the rising and setting of the sun, as we might expect in animals so pre-eminently adapted to a nocturnal life.

Elton *et al.* (1931), experimenting with *Apodemus sylvaticus*, give mean figures for a number of 24-hour tests and show that activity is almost exclusively concentrated in the hours of darkness between 6 p.m. and 4–5 a.m. with two well-marked peaks at 8 p.m. and 2.30 a.m.

Other authors have made experiments to discover what factors govern this strictly nocturnal activity. Johnson (1926) was able to modify the 24-hour rhythm of *Peromyscus* spp., though he could not eradicate it. His animals were kept in continuous darkness and he found that a 24-hour rhythm persisted, though after several months it did not correspond with sunset and sunrise. The provision of light during the normal night reversed the rhythm almost completely and this new rhythm continued after a return to continuous darkness.

On the other hand, Behney (1936) experimenting with the same species found that, although in general they observed a strict 24-hour rhythm, there were conditions in which he observed considerable day-time activity. One of the experimental mice was left without food by an oversight, and under the stimulus of hunger it came out freely during daylight. Similarly during a period when the floor of the outer cages had been covered with a deep layer of snow, considerable daylight activity was recorded from the mice running through the burrows they had made in the snow.

It seems probable that cover rather than light was the factor influencing day-time activity in this last case.

Further work on *Apodemus* by Kalabukhov (1939) throws more light upon the subject, though in some respects his results conflict with those of Johnson. Working with the two species *A. sylvaticus* and *A. flavicollis*, he discovered a rather unexpected divergence between them: both species showed a normal nocturnal activity curve with a peak shortly after dusk (*sylvaticus* also showed a second peak later in the night), but when kept in

total darkness this rhythm broke down in the case of *sylvaticus*, and feeding, though still mainly concentrated during the 'night', was spread out during the 'day' hours. With *flavicollis*, however, the rhythm persisted in darkness for many days in almost the exact form it had before. Thus the latter's behaviour is far less influenced by the alternation of night and day than that of *sylvaticus*, and corresponds more closely with that of *Peromyscus*.

In all this group of small, nocturnal rodents investigated the 24-hour rhythm is proved to be as fundamental as that of rats. The ease with which it can be reversed by interchanging periods of light and darkness as well as the precision with which the onset of activity follows the seasonal shifting of sunset show that normally light intensity guides the expression of the rhythm. Obviously light is the predominant environmental factor: but at times other factors, such as hunger, may temporarily override the importance of light. Thus the basic pattern is the same as that of the rat, and they are equally adaptable in responding to particular circumstances.

Few of the authors mention the short rhythm, yet it is quite apparent in the figures given by Johnson and Behney. It can be most easily seen during the infrequent day-time activity, and is generally of the order of 2 hours in its intervals. Thus there is a descending order in frequency according to the size of the animal, viz. rat, 4 hours, *Microtus* $2\frac{1}{2}$ hours, *Apodemus* and *Peromyscus* 2 hours.

Finally we must consider the work done upon domesticated and wild house mice. Szymanski (1914, 1918) used white mice, 'grey' mice, and Japanese waltzing mice. In his experiments upon white mice no long-term rhythm could be distinguished, a situation similar to that of Richter's white rats: the short rhythm was well-marked and had a periodicity of about $1\frac{1}{2}$ hours. With his 'grey' mice the short rhythm was in cycles of about 1 hour: this difference may be a function of the size of his animals, but he gives no details about this.

With the waltzing mice the long-term rhythm was easy to see. Activity usually increased during the afternoon (though we must remember that the suspended cage technique measures *all* movements) and reached a peak after sunset, then fell slightly and reached another peak in the early hours of the morning. A more detailed study of the same strain of mice by Wolf (1930), who made his records at a feeding tray, showed a rhythm that was similar except that the second peak occurred later (between 5 and 8 a.m.). Further experiments by Wolf showed that this rhythm persists for many days in complete darkness, the only modification being that the first large peak of activity had a larger spread at the base. Young mice, born under these conditions of continuous darkness and removed at an early age from their parents, showed a clear 24-hour rhythm, though in this case it did not correspond with the alternation of day and night outside. The rhythm is therefore inherent in the animal's organization, but needs some guiding to fit it to wild conditions.

Finally there is the work of Hellwald (1931), which is strictly comparable to the experiments described in the present pages, since he used wild *Mus musculus* under conditions of normal day-length and recorded their visits to a food tray only. His records were made for 8 days continuously upon four mice kept in separate cages and the resulting charts are presented in their original form. All the records agree in showing the main feeding period to be between 6 and 11 p.m., with more sporadic feeding continuing until about 5 a.m. From here to 10 a.m. records are very scarce, then sporadic feeding starts again and continues until 6 p.m. This midday feeding is quite as intense as the late night and early morning feeding, and this is the main point in which Hellwald's observations differ from those presented in this paper. When feeding was at medium intensity the interval between visits was from 1 to 1½ hours.

An important point brought out by these data is the individual variation in feeding rhythm, since one animal is clearly more prone to feed in the afternoon than the other three. Such idiosyncrasy is greatly stressed in the following pages. We should, perhaps, expect this in the house mouse, which in becoming a commensal has exchanged an environment with plenty of diurnal enemies for one with few or sometimes none. Thus selection will not demand the uniformly nocturnal habits of *Apodemus* or *Peromyscus*.

To sum up the results of previous work, there is a strong presumption that all these small rodents exhibit a basic short-term rhythm of activity immediately caused by sensations of hunger. This is most easily discerned in domestic strains, where a 24-hour rhythm is not so strictly enforced. The length of the period varies with the size of the animal, viz. rat 4 hours, field vole 2½ hours, wood-mouse 2 hours, house mouse 1–1½ hours.

Superimposed upon this is a very stable 24-hour rhythm, which persists in complete darkness, though the degree to which the rhythm moves out of phase with external conditions varies even between closely related species. This long rhythm is more accentuated in wild nocturnal species, which normally show a clear-cut distinction between the end of the resting period and the beginning of the feeding period. This is most distinct in *Apodemus* and *Peromyscus*, less so in *Mus*, while in *Microtus* the passing from day to night merely means the intensification of rhythmical activity already present.

3. MATERIAL AND METHODS

All the experimental animals used in the tests to be described were wild *Mus musculus* caught in corn-ricks near Oxford. They were kept in large stock cages, each 2½ ft. square by 1 ft. high, in which was placed plenty of litter (hay or chaff) and a number of small cover boxes, which made handling the mice easier. Their food was rolled oats or whole wheat supplied in excess of their requirements; fresh water was given every day and green food about once a week. Under these conditions 20–40 mice could be kept in each cage, and maintained in good health. Animals used in the experi-

ments were all adults and usually about 15–20 g. in weight; smaller animals were sometimes used, but these were never below 10 g. in weight.

The experimental cage was one of the stock cages mentioned above divided into three compartments. At one end of each compartment was a feeding tray mounted on a wooden framework, which allowed the tray to tip at either end under the weight of the feeding mouse. Such a movement made contact between two nickel points, one beneath the tray and the other fixed adjustably in the framework supporting the tray (see Plate 4a). The closing of the circuit energized an electro-magnet in the recording apparatus, thus pulling up a pricker arm against a waxed strip, which was revolving on a drum (see Plate 4b). Each of the three compartments was wired up in the same way, so that three concurrent records of activity could be made in parallel lines on the same waxed strip. In this way each visit to the food tray was recorded as a small hole in the strip, and, when the experiment was over, these strips, each representing 24 hours' records for the three mice, were printed in a multigraph apparatus upon charts that had already been prepared.

The procedure during an experiment was as follows. First three mice were chosen from the stock cages, weighed and sexed, and placed one in each compartment. Each was provided with a cover box, a small amount of hay, with which it usually made a nest in the cover box, and a supply of water and food. The food was placed in the special recording tray except where the purposes of the experiment demanded otherwise. Two days were allowed for the mice to settle down, then a weighed amount of food was provided and the recording apparatus started. The daily amount of food taken was checked every morning at 10 a.m., and at the same time a new strip was placed on the drum, the contact points beneath the trays scraped clean and the functioning of the apparatus tested.

Conditions under which the experiments were done were as follows. The majority were carried out in a cellar lit by artificial light, which was controlled by a time clock. The usual amount of light was 11 hours with 13 hours of darkness (5 p.m. to 6 a.m.), except in some of the later experiments, where for convenience an arrangement was adopted providing 12 hours of darkness from 9 p.m. to 9 a.m. Since this cellar was heated during the winter, there was not much variation in temperature (18–22° C.) throughout the year, but relative humidity during the period when the cellar was heated dropped to about half of its summer value of 70–80%. Apart from this, a few of the experiments were done in a shed with normal day-length, but these were done at a time of year when there was little difference from the cellar conditions.

The apparatus had certain limitations. The drum upon which the records were made revolved once in 24 hours, travelling about half an inch in 1 hour. This meant that single records might be multiplied over about 3 minutes without making more than one distinguishable record. However,

all that this does is to apply a measure of smoothing to the data, a procedure which would be needed in any case. In fact, the simplest and most satisfactory way of interpreting the charts, which has been followed throughout this paper, is to split up each hour into 6-minute periods and record each such period as plus or minus. An index figure is given to each hour, representing the number of 6-minute periods with positive records; that is to say that the maximum for each hour is ten.

Another difficulty was that a small percentage of visits to the feeding trays was found to go unrecorded. This must have meant that occasionally mice were able to climb up on to the pivot that supported the tray and take food from its mid-line, so that it was not tipped. Since figures from the special experiments described below show that this did not occur very often, the results are probably not seriously disturbed.

We first planned a special series of experiments to test the relation of the activity recorded by the charts (*a*) to actual food consumption, and (*b*) to the actual number of individual visits. We had to eliminate the possibility that feeding might vary much in intensity, and thus visits appearing equal on the charts might represent very different amounts of food taken. It was equally necessary to check whether chart records might represent very different numbers of individual visits to the food tray (i.e. beyond the limits of separate recording).

Accordingly during the main feeding periods of 4 days hourly weighings were made of the amount of food in the trays to be compared with the index of activity derived from the charts. Also, for one day an electrically operated counter was included in the circuit of one compartment, which recorded the number of actual visits, and this total was checked every hour at the same time as the food was weighed. The results were very interesting and showed that the charts did give a true picture of feeding rhythm, when interpreted in the way described.

The relevant data from these experiments are assembled in Table 21, where the food taken and the activity index for each of two mice (B and C in the table) on separate nights are given side by side at hourly intervals. If all these data are combined into a single correlation table the resultant coefficient is significant ($r = 0{\cdot}4132$, and since $n = 92$ the probability of the observed variations being due to chance is less than 0·01). If each mouse and night are taken separately, the coefficients of correlation vary as shown in Table 21, but, if a statistical test is made of the degree of this variation, it can be shown that it may quite easily have arisen by chance (for the test between individual values $\chi^2 = 6{\cdot}88$, and since $n = 7$, $P =$ more than 0·30). There is therefore no evidence that the differences between nights and between the two mice are significant, so that the positive result of the single correlation table is due in equal measure to each of the groups of data considered.

From these considerations it is safe to conclude that the activity index

TABLE 21

	Hours	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
1 Nov.	B													
	Food taken	–	0·05	0·42	0·05	0·42	0·06	0·57	0·36	0·51	0·11	0·03	0·11	
	Activity	2	4	0	4	3	6	4	8	2	1	4	0	
							$r = 0·0531$							
2 Nov.	B													
	Food taken	0·14	0·29	0·01	0·30	0·26	0·63	0·33	0·22	0·56	0·04	0·29	0·00	
	Activity	4	6	1	8	8	8	6	6	6	1	3	0	
							$r = 0·7654$							
5 Nov.	B													
	Food taken	0·36	0·44	0·40	0·20	0·06	0·39	0·06	0·34	0·21	0·45	0·35	0·16	
	Activity	5	4	4	2	3	9	2	7	8	10	9	9	
	Counter	13	16	17	6	8	35	5	28	29	31	33	12	
							$r = 0·4326$							
6 Nov.	B													
	Food taken	0·02	0·32	0·50	0·13	0·49	0·18	0·28	0·46	0·20	0·23	0·02	0·05	
	Activity	1	4	3	2	7	3	7	10	7	8	7	2	
							$r = 0·4344$							

	Hours	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
1 Nov.	C													
	Food taken	–	0·04	0·29	0·06	0·36	0·25	0·17	0·21	0·33	0·10	0·62	0·32	
	Activity	0	0	5	2	7	8	6	5	5	2	4	3	
							$r = 0·6298$							
2 Nov.	C													
	Food taken	0·18	0·01	0·47	0·04	0·08	0·31	0·29	0·25	0·27	0·31	0·21	0·32	
	Activity	0	0	3	0	5	7	5	4	3	5	2	5	
							$r = 0·5572$							
5 Nov.	C													
	Food taken	0·27	0·23	0·22	0·21	0·23	0·22	0·10	0·26	0·20	0·28	0·22	0·17	
	Activity	2	6	2	1	1	5	1	1	1	2	7	4	
							$r = 0·0545$							
6 Nov.	C													
	Food taken	0·05	0·21	0·32	0·15	0·23	0·33	0·22	0·24	0·11	0·25	0·14	0·19	
	Activity	0	4	5	7	3	1	1	1	0	0	1	2	
							$r = 0·2238$							

Figures for mice B and C upon which correlation table is based are in g. Activity is read from the charts counting each 6-minute period with a record as a unit (i.e. highest possible in 1 hr. = 10).

N.B. The 24-hour clock is used in all the tables for convenience.

based on the charts reflects accurately variation in the rate of actual feeding and that activity due to other causes is not obscuring the results.

Records made by using the electrical counter are shown in Table 21 for one mouse on 5 November. These show that the actual number of separate visits to the food tray is positively correlated with the activity index based on the charts ($r = 0{\cdot}82$ and for 11 degrees of freedom P is less than 0·01). This result allays any suspicion that the shortcomings of the recording method are disguising a large variation in the number of individual visits. It is important to clear up this point because, when we come to consider 'sample take' in mice (see later), we need to know the number of actual visits to the feeding tray per unit of time and whether the rate of visiting varies throughout the period of feeding activity. Now we can be sure that this rate of visiting will vary only in concert with increase and decrease of the chart index.

4. THE NORMAL FEEDING RHYTHM OF THE HOUSE MOUSE

The total number of experiments carried out represents 109 24-hour periods with records of the activity of three mice for each period, a total of 327 separate records. Two statistical tests were first carried out on samples of these data to determine whether there was any significant variation between the records for individual mice, or, in the case of continuous records of a single mouse, whether there was variation between days.

The first test was made on the results of four experiments with three mice, each of which continued over 2 days (Table 22). From a superficial inspection of the totals of columns and of ranks, it seems probable that the variation between 2-hr. periods is much greater than that between experiments. For analysis, figures were worked out from the activity index for 2 days and for 2 hours, expressed as a percentage of the possible maximum of forty for each entry. Analysis of variance was carried out by transformation of these figures into angles (see Fisher and Yates, 1948) and the results indicate that the variation between 2-hour periods is significant, while that between experiments is not significant.

Thus all the mice tested were behaving consistently and we need not test the significance of differences between sexes and ages. All mice vary in their feeding activity from hour to hour and the 24-hour rhythm indicated is constant throughout the experiments chosen.

Since the bulk of the experiments have only records of 2 days for individual mice, we thought it wise to test the results of an experiment on a single mouse, which was run for 9 days, to see whether the rhythm was consistent from day to day. An analysis of variance carried out in the same way as above confirmed that this was so. Table 23 gives the original data, upon which the analysis was based.

With these points now cleared away we can turn to the complete figures for the 109 days during which records were taken. We have excluded from

TABLE 22. *Activity index figures for two days for twelve mice*

Hours	Expt. 107a	107b	107c	108a	108b	108c	109a	109b	109c	110a	110b	110c	Total	Per cent. of maximum possible
	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2	Day 1 2		
10	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	7	1·5
11	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 6	0 0	0 0	0 0		
12	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	4 2	0 0	0 0	1 0	16	3·3
13	0 0	0 0	0 0	0 0	0 0	6 0	0 0	0 0	0 0	1 0	1 0	0 1		
14	0 0	0 0	0 0	0 0	0 0	1 0	0 0	0 1	0 0	0 0	0 0	2 2	40	8·3
15	0 0	0 0	0 0	0 1	2 4	0 4	0 0	7 2	0 0	4 5	2 3	0 0		
16	0 0	0 0	0 0	1 0	4 0	0 0	1 1	4 2	3 0	0 2	0 3	0 0	62	12·9
17	2 0	0 0	3 0	2 2	6 1	4 1	1 0	1 3	0 5	1 0	1 1	3 4		
18	0 0	3 0	2 4	1 0	4 4	1 4	2 1	0 3	5 0	3 0	2 0	0 0	93	19·4
19	3 0	1 2	2 3	4 1	3 3	4 3	2 2	4 2	5 4	0 0	0 0	3 3		
20	3 2	3 5	1 1	2 4	4 3	5 3	4 3	5 3	5 4	0 7	3 1	0 2	173	36·0
21	2 3	3 10	6 5	2 3	4 0	4 0	4 3	7 1	4 3	8 5	6 5	9 3		
22	1 6	5 8	2 5	3 2	3 0	1 0	3 1	6 2	3 2	2 5	6 5	7 7	176	36·7
23	5 6	4 5	2 2	2 4	4 0	1 0	2 3	6 1	6 4	7 6	4 5	9 3		
0	1 6	7 1	2 4	0 2	2 2	5 2	1 2	7 3	5 2	8 3	3 5	8 7	148	30·8
1	2 2	5 0	4 3	2 5	1 0	2 0	0 2	9 4	2 0	2 3	3 3	5 1		
2	2 6	0 4	6 2	3 2	3 2	3 2	2 0	0 3	0 0	0 0	0 0	2 1	81	16·9
3	0 5	2 8	4 2	1 3	2 2	0 2	0 0	0 1	3 0	0 0	0 0	0 3		
4	0 5	8 1	4 0	0 0	0 0	1 0	0 3	2 0	0 0	6 1	1 3	1 0	75	15·6
5	0 3	5 0	0 2	0 0	0 0	0 0	5 3	3 0	0 0	2 0	6 5	4 1		
6	0 2	6 7	2 2	1 3	2 0	0 0	2 6	6 2	0 5	5 1	3 7	4 0	148	30·8
7	1 0	1 7	5 1	2 3	3 3	1 3	3 4	5 2	7 5	7 6	5 2	3 3		
8	1 4	3 3	3 0	0 1	0 3	0 3	4 2	0 1	6 7	3 4	4 1	3 0	65	13·5
9	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 0	2 1	1 2	0 0	2 0		
10														
Total	73	117	84	62	74	66	72	109	111	110	99	107	1,084	
Per cent. of maximum possible	15·2	24·4	17·5	12·9	15·4	13·8	15·0	22·7	23·1	22·9	20·6	22·3		

these figures any experiment in which there was experimental alteration of the feeding rhythm, except in the special cases described below.

The figures from these experiments fall into two sections. First there are the results from charts made under a light periodicity approximating to autumn or late winter (13 hrs. of darkness from 5 p.m. to 6 a.m.). For this there are records for a total of 76 days. The procedure has been to sum the

TABLE 23. *Experiment 103c. Activity index figures for one mouse on nine consecutive nights*

Hours	*13–14 Aug.*	*14–15 Aug.*	*15–16 Aug.*	*16–17 Aug.*	*17–18 Aug.*	*18–19 Aug.*	*19–20 Aug.*	*20–21 Aug.*	*21–22 Aug.*	*Total*	*Per cent. of maximum possible*
10											
	0	0	0	0	0	0	0	0	0		
11										0	0
	0	0	0	0	0	0	0	0	0		
12											
	0	0	0	0	1	0	0	0	0		
13										8	4·4
	3	0	0	0	0	2	0	2	0		
14											
	0	1	0	0	0	0	0	0	0		
15										6	3·3
	3	2	0	0	0	0	0	0	0		
16											
	1	1	0	3	2	3	0	0	3		
17										21	11·7
	1	0	0	0	0	2	3	2	0		
18											
	4	0	0	2	3	4	0	2	5		
19										51	28·3
	2	4	2	5	2	6	5	2	3		
20											
	6	4	2	5	9	7	5	7	3		
21										67	37·2
	2	8	4	0	0	0	5	0	0		
22											
	4	1	0	0	0	0	1	2	0		
23										22	12·2
	6	0	2	0	0	0	0	3	3		
0											
	0	4	4	7	0	4	0	0	2		
1										36	20·0
	0	3	0	0	6	1	4	1	0		
2											
	3	3	0	0	0	6	0	5	5		
3										59	32·8
	6	4	2	4	5	4	5	2	5		
4											
	2	3	7	7	8	6	2	9	7		
5										81	45·0
	5	3	5	0	1	0	6	6	4		
6											
	0	0	1	0	0	0	1	0	0		
7										7	3·9
	0	2	1	0	0	2	0	0	0		
8											
	0	0	0	0	0	0	0	0	0		
9										0	0
	0	0	0	0	0	0	0	0	0		
10											
Total	48	43	30	33	37	47	37	43	40	358	
Per cent. of maximum possible	20·0	17·9	12·5	13·8	15·4	19·6	15·4	17·9	16·7		

index figures for each hour throughout the 24, and to express the resultant totals as percentages of the maximum possible activity figure for the 76 days (since 10 is the highest index for each hour, the maximum in this case is 760). The histogram derived in this way is shown in Fig. 6 with the artificial dusk and dawn indicated by dotted lines. From this we can see that

feeding during the day-time is slight. A 24-hour rhythm is well-marked with a slight increase of activity in daylight, just before 'dusk' and just after 'dawn'.

Within the period of darkness there is considerable variation. Activity increases at the beginning fairly quickly, and reaches the highest peak of the night in the hour between 8 and 9 p.m. For the rest of the night activity remains at a moderate level (on the average about a quarter of the available

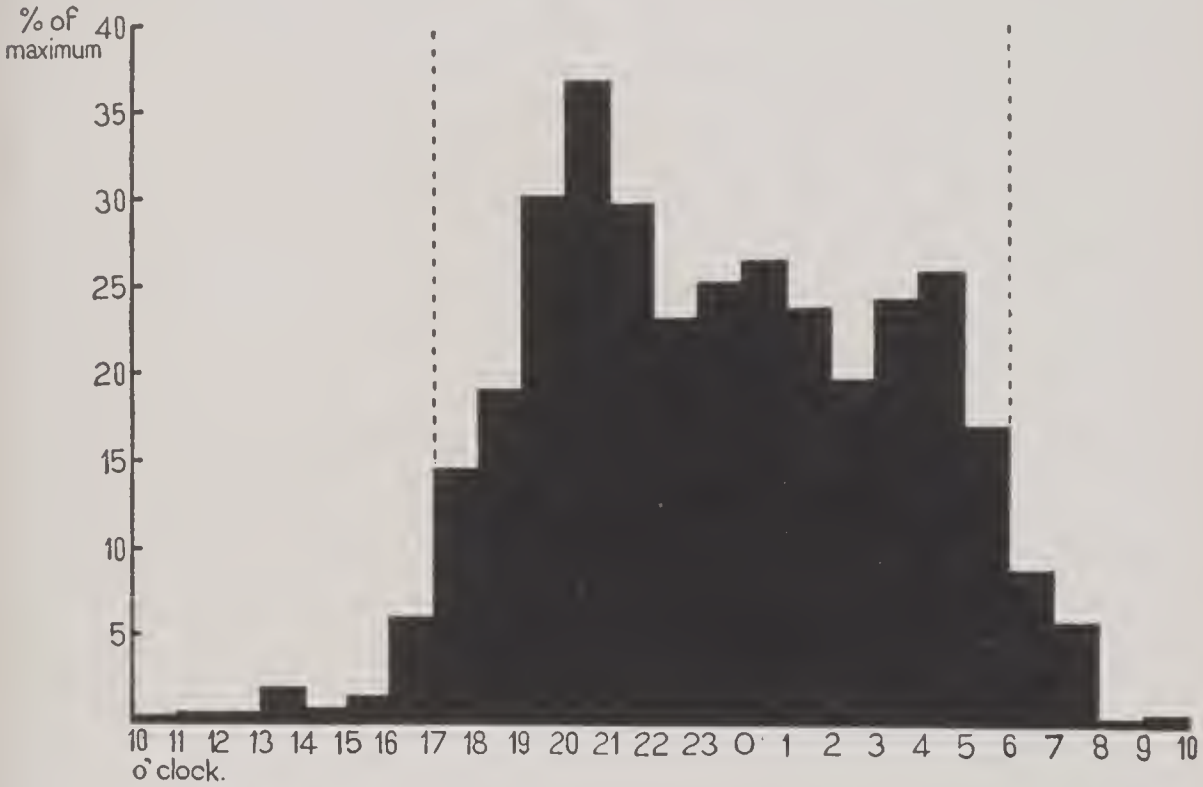


FIG. 6. Feeding rhythm of house mouse with 11 hours' daylight (for detailed explanation see text).

time is spent feeding), though with smaller peaks, which may merely be accidental, until about an hour before the light reappears, when feeding falls off at about the same rate as it started.

If we compare this with the histogram which Elton gives for *Apodemus* two differences are immediately apparent; the onset of activity at dusk is not nearly so sudden and there is no sign of two distinct peaks during the night.

It is very interesting to compare Fig. 6 with the results obtained under different lighting conditions. The histogram in Fig. 7 is derived from charts taken during 33 days under the same conditions as before except that the time clock was fixed to go off at 9 p.m. and on again at 9 a.m. The actual time of darkness is not much less than in Fig. 6, yet feeding activity has been spread out over a longer period. Even during the middle of the day feeding is more marked than under the previous conditions, while still more activity, increasing slowly and fairly evenly, occurs between 3 and

9 p.m. Finally, the spreading of the total period of feeding has resulted in a well-marked bimodality in the figure.

The main peak of feeding activity occurs about the same hour under both conditions of lighting, though where there is darkness from 5 p.m. onwards the onset is later and quicker. On the other hand, where darkness continues later feeding rises to a second peak and drops off much more abruptly. In this case, therefore, bimodality is not coincident with a long day resting

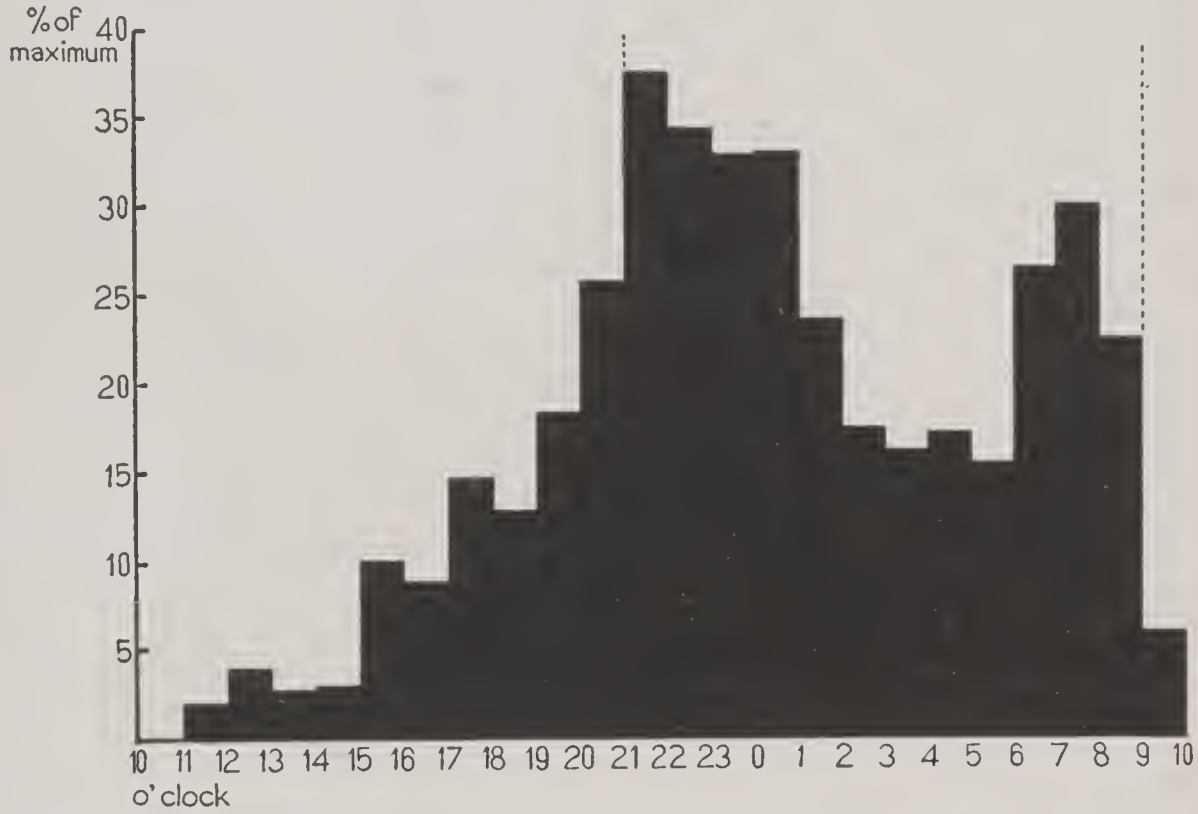


FIG. 7. Feeding rhythm of house mouse with 12 hours' daylight (for detailed explanation see text).

period, as appeared likely in *Peromyscus* and *Apodemus*, but with a spacing out of feeding.

The feeding rhythm of the house mouse is therefore variable, though in general it falls between the two extremes (for wild animals) exemplified by *Microtus* and *Apodemus*. This makes it less remarkable that Hellwald's results should contain the one striking difference of having day-time activity equal to or greater than late night activity.

5. EXPERIMENTAL REVERSAL OF DAY–NIGHT RHYTHM

In this experiment the 24 hours were divided for convenience into two equal parts, the division falling at 10 p.m. Fig. 8 is self-explanatory and gives the actual sequence of feeding activity throughout 17 days. The records are again reduced to 6-minute units, each being blocked in when there is a mark on the chart at any point in the unit. For the first 6 days darkness occurred from 10 p.m. to 10 a.m. and most feeding activity was

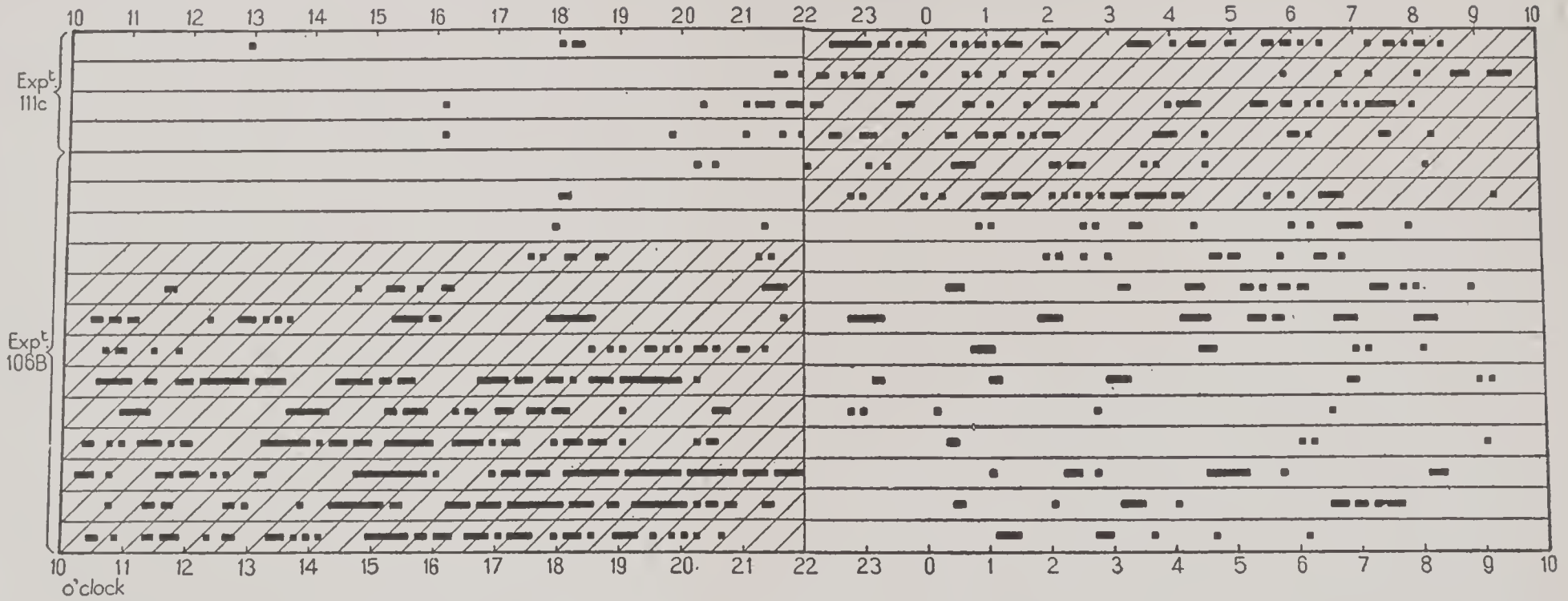


FIG. 8. Change in feeding rhythm of house mouse owing to reversal of 'day' and 'night'. The shaded areas show when the light was switched off. Thick lines show activity in units of 6 min. Records for the first 4 days from Experiment 111*c* extend for comparison the period of the original rhythm.

concentrated in this period. On the seventh day the light was left on the whole time, and this suppressed activity during the latter half of the day. The next day started the reversed rhythm, and through the next 4 days activity gradually became more concentrated during the early part of the day. From the twelfth day onwards this part of the day shows quite as intense activity as the other part did before reversal. To this extent the feeding rhythm was successfully reversed. However, if the amount of activity for the lighted hours is compared during the two phases of the experiment, persistence of the old rhythm is seen in the increased 'daylight' activity after reversal.

Under these conditions the feeding rhythm is not entirely controlled by the relations of light to darkness, and the persistence of the original 24-hour rhythm is quite perceptible. This is probably a further instance of the variability of the feeding behaviour of the house mouse: under experimental reversal of night and day a latent tendency towards daylight activity, already shown in the work of Hellwald and in Fig. 7 above, reveals itself.

6. THE SHORT-TERM RHYTHM

This is not easily discerned from the charts owing to the pronounced nature of the 24-hour rhythm. Nevertheless experiment 103, which ran for 9 consecutive days with the same three mice, gives some information. A frequency distribution was constructed of the periods between the beginning of one spell of activity and the beginning of the next (see Table 24). The figures are again treated in units of 6 minutes, and any break of 12 minutes or less is taken arbitrarily as being only a temporary cessation of feeding, i.e. is not counted for the purpose of the analysis.

TABLE 24. *Occurrence of short-term rhythm in feeding of individual house mice*

	Length of time (in 6-min. units) between two successive periods of feeding activity																
Minutes .	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114 and over
Frequency	0	3	6	9	6	13	16	13	17	14	9	7	6	6	7	2	48

This table shows a tendency for one period of feeding to be followed by another more frequently at intervals of $\frac{3}{4}$ to $1\frac{1}{4}$ hours than at longer or shorter times.

This analysis suggests a slight correction to the estimation of $1-1\frac{1}{2}$ hours between feeds made from Hellwald's data, though the latter was admittedly rough. Such a result indicates a gradient in length of the short-term rhythm coinciding with size, viz. house mouse $\frac{3}{4}-1\frac{1}{4}$ hours, *Microtus* about $2\frac{1}{2}$ hours, and the rat 4 hours.

We may summarize the normal feeding rhythm of *Mus musculus* as

follows. There is a basic tendency for a mouse to feed every $\frac{3}{4}$–$1\frac{1}{4}$ hours, but this is largely suppressed during the day. Feeding is most frequent during the night and occurs at a fairly constant rate; however, if the onset of darkness is retarded, mice may feed fairly frequently during the last hours of light and this makes a difference to the shape of the feeding curve, which rises more slowly and has two well-marked peaks, the second occurring just before daylight. Other authors have shown that day-time feeding frequently occurs, though the actual factors controlling this are obscure. This is similar to the variation in the amount of daylight feeding that can be induced in rats (see work by Chitty cited on p. 73). That the day–night rhythm is important we learn from the reversal experiment, which induced the peak of activity to take place during the morning instead of at night, though the persistence of the original rhythm is still shown by moderate activity during the night.

7. DISTRIBUTION OF FEEDING BETWEEN DIFFERENT POINTS

We now know in general the basic pattern of the feeding rhythm in mice; the next thing to ascertain is how this feeding is distributed in space.

For this purpose we removed the compartments from the experimental cage, so that one mouse could have access to three separate feeding trays, each wired to the recording apparatus. Charts for 17 successive days were obtained, showing the way in which the mouse patronized the various trays. It is obviously important to know whether a mouse, when faced by a number of alternative sources of food (simplified by being reduced to three in the experiment), will visit all three during a single burst of feeding activity, or whether it is more inclined to fix on a favourite tray and use this to the neglect of the others. It is also possible that each spell of feeding activity may be concentrated particularly on one tray, even though another tray may be used at the next visit. In the table below the activity index figures are given summed for the whole 17 days (i.e. maximum for each entry is 170).

TABLE 25. *Activity index figures for hours during the main feeding period*

O'clock	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Point 1	1	3	2	11	18	22	18	12	20	11	14	13	13	9	7	8	11	6	0		199
Point 2	1	3	4	8	13	27	21	13	18	11	8	18	14	12	7	9	8	1	1		197
Point 3	3	14	5	11	20	14	6	9	8	15	6	13	9	2	7	5	2	9	0		158
Total	5	20	11	30	51	63	45	34	46	37	28	44	36	23	21	22	21	16	1		554

One mouse was used and the figures are summed over 17 days. The three points represent three feeding trays with the same food in each.

From this table we can see without any further analysis that, when a mouse comes out for a feeding spell, it tends to visit all the available points, and that this tendency is constant from spell to spell and throughout the feeding period. This does not mean that there is no selection at all; indi-

vidual hours do show differences between the use of the three points, and taking the figures together point 3 was patronized less than the other two.

This experiment suggests that an even larger number of feeding points, provided that they were all in the mouse's range, would be visited during each feeding spell. This is in accord with the intense searching behaviour of a mouse throughout its range, which has been described previously (see Ch. 2).

8. AMOUNT OF FOOD EATEN EACH DAY

In the previous sections we have discussed the distribution of feeding activity in the house mouse in space and time. We must now relate this activity to the actual amounts of food taken.

Throughout all these experiments we used dry rolled oats most frequently because choice tests (see Ch. 7) had shown that mice preferred it to most other baits. In some of the experiments, especially where discrimination between two foods in various circumstances was tested, the mice were given whole wheat.

The average daily consumption of these two foods by adult mice has been discussed in Chapter 3. The amounts are: rolled oats $3{\cdot}552 \pm 0{\cdot}107$ g., whole wheat $3{\cdot}400 \pm 0{\cdot}224$ g.

The correlation between hourly food consumption and activity index, which was demonstrated on page 78 gives good ground for assuming that the curve of feeding activity does in fact represent intensity of feeding. We may therefore derive figures for the hourly consumption of food throughout the night from the mean figure for daily consumption and the distribution of activity from hour to hour given in Fig. 6. This may seem a roundabout way of getting at the result, when Table 21 contains data on hourly consumption of wheat measured directly. However, the activity rhythm in this experiment of reversing light and darkness was not quite typical, and it seems best to use the figures for activity and consumption which are calculated from a large number of experiments.

The expected consumption from hour to hour is shown in Table 26 and it is clear that the highest amount eaten in an hour even at the peak of the night's activity is quite small, in fact well under half a gram. Furthermore, supposing that this feeding is distributed among several points, the amount taken from each will be correspondingly reduced even if the patronage of the points is equal.

TABLE 26. *Distribution of mean daily consumption of food by hours based on the activity curve in Fig. 6*

O'clock	10	11	12	13	14	15	16	17	18	19	20	21	22
Take (mg.)	3	5	3	20	7	15	61	148	194	312	372	302	

O'clock	22	23	0	1	2	3	4	5	6	7	8	9	10
Take (mg.)	236	256	269	242	201	247	274	172	89	58	1	5	

Finally, feeding does not begin suddenly: there is always a period about dusk, or even extending back into the afternoon (see, e.g. Fig. 7), when the consumption is working up from even smaller amounts. So it is easy to see that the hourly consumption of house mice is never very large and may often be extremely small, in the tens instead of in the hundreds of milligrams.

9. NUMBER OF VISITS EACH DAY

As explained before, in a certain number of experiments the actual number of visits paid to the recording trays was checked by means of an electrical counter. The charts only record feeding activity in terms of positive or negative 6-minute periods, so that this extension of the information is valuable. In the first place it gives a good measure of the diffuseness of the feeding activity of the house mouse; in the second place it will give a rough idea of the amount of food taken at each separate visit.

We showed on page 80 that the number of visits bears a constant relation to the amount of food eaten, but this does not imply that at each visit food is necessarily taken. All we can say is that the ratio of feeding visits to non-feeding visits remains the same. To test this an experiment was done in which the food was provided in a tin away from the recording tray; records made by tilting the latter would therefore be due to casual running about.

The charts for 6 nights give a mean of just under five positive 6-minute periods per night. Comparing this with totals for typical feeding activity, as shown, e.g. in Table 28, it can be seen that non-feeding activity probably composes a fairly small percentage of the records (*c.* 12). The number of feeding visits can therefore be roughly estimated as some 88% of the total.

By means of the counter the daily number of visits to the food tray made by one mouse was checked for 17 consecutive days, giving the following figures: 199, 239, 164, 206, 223, 216, 208, 234, 161, 137, 106, 173, 256, 301, 246, 244, and 312. These give a mean value per night of 219 visits, and 88% of this is about 193. This estimate of the number of feeding visits should only be regarded as a rough approximation, but it is sufficient to show that the feeding behaviour of a house mouse during each spell of activity is extremely 'nervous' and consists of a great number of very short visits. Each positive record on the charts probably represents about five separate journeys, and, if we suppose that at each visit a mouthful of roughly the same size is taken, this means that each is of the order of 20 mg. of food. Of course there will be very great variation, for a number of dubious assumptions have been made in reaching this figure, but the calculations are enough to show the small amounts of food that are being dealt with.

Before analysing the way in which mice approach different kinds of plain food we may point out that with a bait containing 5% of zinc phosphide a mouse would take at each visit only about 1 mg. of the poison. If, as in

field conditions, only a small proportion of the available food is poison bait, such a dose, which is barely lethal, may not be repeated for a considerable time, if at all.

10. INDIVIDUAL VARIATION IN ACTIVITY

In the previous sections we have discussed the basic feeding rhythm of house mice, using data from many experiments to show the general pattern of distribution and intensity of their feeding. From these results we begin to see that the diffuse way in which mice feed makes poison-baiting by routine methods, such as those worked out for the brown rat, unlikely to succeed on account of the small amounts of food taken.

However a reduction of less than 90% of the population from poisoning can be considered a failure, so we must take into account everything that may help some of the mice to escape. In this section we consider briefly some of the main types of individual variation in feeding behaviour.

In the first place mice vary between themselves in the total amount of feeding activity displayed in any one night. The frequency distribution given in Table 27 shows the arrangement of the total activity for each night throughout the experiments. Since a single mouse was usually recorded for 2–3 nights only, the components of the total will be mainly due to individual characteristics.

TABLE 27. *Distribution of total amount of feeding during single nights, expressed as the summed hourly activity index per cent. of its maximum value*

Activity index per cent. maximum	*Frequency*
4 and under	3
5–6·9	6
7–8·9	6
9–10·9	8
11–12·9	11
13–14·9	11
15–16·9	21
17–18·9	12
19–20·9	15
21–22·9	3
23–24·9	3
25–26·9	5
27 and over	3

From this table we see that, although the greatest frequency occurs between 15 and 17%, nevertheless in many instances the mice made feeding visits more frequently (17–21%), and presumably took less food at each visit. Although these instances are balanced in the table by the entries for 11–15%, making a frequency distribution which is fairly symmetrical, the class of more frequent feeders may be more difficult to poison.

Similarly mice may vary between themselves in the number of actual visits they pay to the bait points. Records with the electric counter were made for 32 nights and the totals are distributed as in Table 28.

TABLE 28. *Distribution of totals of daily visits to food tray from 32 days' records*

No. of visits	*Frequency*
100–25	2
125–50	2
150–75	6
175–200	0
200–25	7
225–50	5
250–75	3
275–300	1
300–25	4
Over 325	2

Here again, although the mean is something over 200 visits per day, there are plenty of records with half as many visits again, and these must have meant a decrease in the average amount of food taken at each visit.

Furthermore the amount of food taken varies from day to day. We discuss this in Chapter 3, but must allude to it again here, because it helps to explain the frequently experienced recurrence of low takes during field baiting.

Apart from these, there are many qualitative kinds of variation in behaviour, which, though difficult to evaluate, have an evident effect on the result of field poison trials. We have already drawn attention to the instance in Hellwald's results where one mouse was particularly addicted to daytime feeding. This kind of thing is amply confirmed in the present series of experiments. Furthermore, there is considerable variation between mice in the time when they begin their main feed. This is important because the later this begins, the hungrier the mice are likely to be and the more food will be taken in the first half hour. There is also variation in the extent to which mice will take food from the tray and carry it into their cover boxes. This trouble is not serious with rolled oats, since the flakes are not usually carried away, but with whole wheat it is different. Some of the mice carried an appreciable amount of food back and ate it in the cover boxes. This was strikingly illustrated in one experiment, where the light was left on all night by mistake. One mouse was unaffected, but the other two had eaten nearly all their food in the boxes. This is easily verified because of the nibbled dust which is left wherever food has been eaten.

Another idiosyncrasy, well illustrated in the charts, is the speed with which the main feeding period commences. Generally mice work up gradually to their highest intensity of feeding, but they vary widely: some will start to

make occasional visits during the afternoon and these gradually become more frequent as the evening approaches; others make occasional visits during late afternoon and then suddenly intensify their activity; with others again there is no feeding until the sudden evening onset. Clearly the last will be far more liable to eat a lethal dose of poison.

Thus the general approach to the problem of poisoning mice is shaped first by a knowledge of the basic feeding behaviour pattern, which shows the conditions to be established for eliminating the majority of the mice: and then by knowing at least roughly the limits of individual variation so we can judge what further refinements in technique must be made for dealing with the small but difficult minority of the population. These happen to be protected from poison campaigns (which after all are only a special form of predation) by their general variability in behaviour, and will remain to build up the population again and (one must suppose) to transmit their successful characters to their offspring.

Even so, individual variability only becomes of paramount importance (from the point of view of this analysis) when the question of approach to different kinds of food is investigated.

II. APPROACH TO NEW FOODS AND TO NEW SITES

In the previous sections we have described the characteristics of the house mouse's feeding behaviour under the most simplified conditions. The nature of this behaviour has already revealed several generalizations of importance for control in the field. It also serves as a basis for investigating what happens when the mice are faced with certain choices between plain baits or between feeding points, which reproduce in a simplified way conditions in the field. In shops and houses we cannot usually exclude mice from all sources of food, and therefore the baits we lay in our endeavour to control the mice have to compete with their normal food. This competition may be between new and accustomed feeding points, or between new and accustomed food.

In the following sections we have analysed principally the competition between feeding points. Competition between foods has been studied only between those known to be equally palatable to mice, that is to say that it is the reaction to change in itself and not the reaction to less or more palatable food that is investigated. This latter subject is treated in Chapter 7.

The experiments on the ranges of house mice and the extent to which they are searched (see Ch. 2) have already shown that mice will at once investigate new sources of food introduced into their ranges. Similarly, previous experiments with the activity-recording machine (see section 7 above) have shown that several food points in the range of one animal may each be visited during a spell of activity, though the actual amount of food taken may vary. These results make it unlikely that mice will overlook any new

baits through lack of inquisitiveness or through shyness. For successful control the important thing to find out is how the mice divide their attention between new and accustomed baits, whether in terms of time spent or of actual food eaten.

Conditions in these experiments were similar to those previously described. The choice for testing reactions to change of food was confined to rolled oats and whole wheat. These are roughly equivalent in calorific value and are both eaten eagerly by wild mice. Thus any reaction due to preference, as distinct from the effect of being accustomed to one of the foods, is minimized.

For testing the reactions due to change of food site, the recording tray in each compartment was used as one site and a tin, which could be placed in any other position in the compartment (i.e. on or off the main runways) was used as the other. Sometimes the new site provided the records on the charts, sometimes the old. Thus any change in feeding rhythm was checked in two ways.

From these results we found that the reaction to a new site was not always the same, and there was no means of predicting what any single mouse would do. In no case was a new food site entirely neglected (even if weighing the food betrayed no eating, the charts showed visits), but the degree of attention might be great or small, and, if great, there was no guarantee that it would remain so.

Before examining these results quantitatively we must see what kind of information the charts provide about the method of changing from one feeding site to another. Fig. 9 shows the feeding activity of three mice (according to previous conventions) for eight consecutive nights. The interrupted perpendicular lines indicate the times at which the light was switched off and on. The arrows between days 2 and 3 indicate where a change was made in the feeding site. Above these whole wheat was provided in tins in the middle of each compartment, and trays wired to the recording machine were left empty (hence the occasional records of the first 2 days are due to 'activity' only). Below the arrows dry rolled oats also was provided in the trays, so that each mouse had a choice between whole wheat in the tins and oats in the trays. This experiment in fact introduces the complication of choice between foods as well as between sites, but it illustrates the main points so well that it has been presented in full in spite of this drawback.

The change in behaviour after the choice was offered can best be considered under two headings.

(*a*) Considerable diversion to new source. All three mice in Fig. 9 show that at first half or more of their normal consumption is taken from the new food supply, though the third mouse changed back again later. These tendencies can be read off from the figures on the left-hand side: above the arrows consumption of wheat, the sole food, is given; below the arrows the

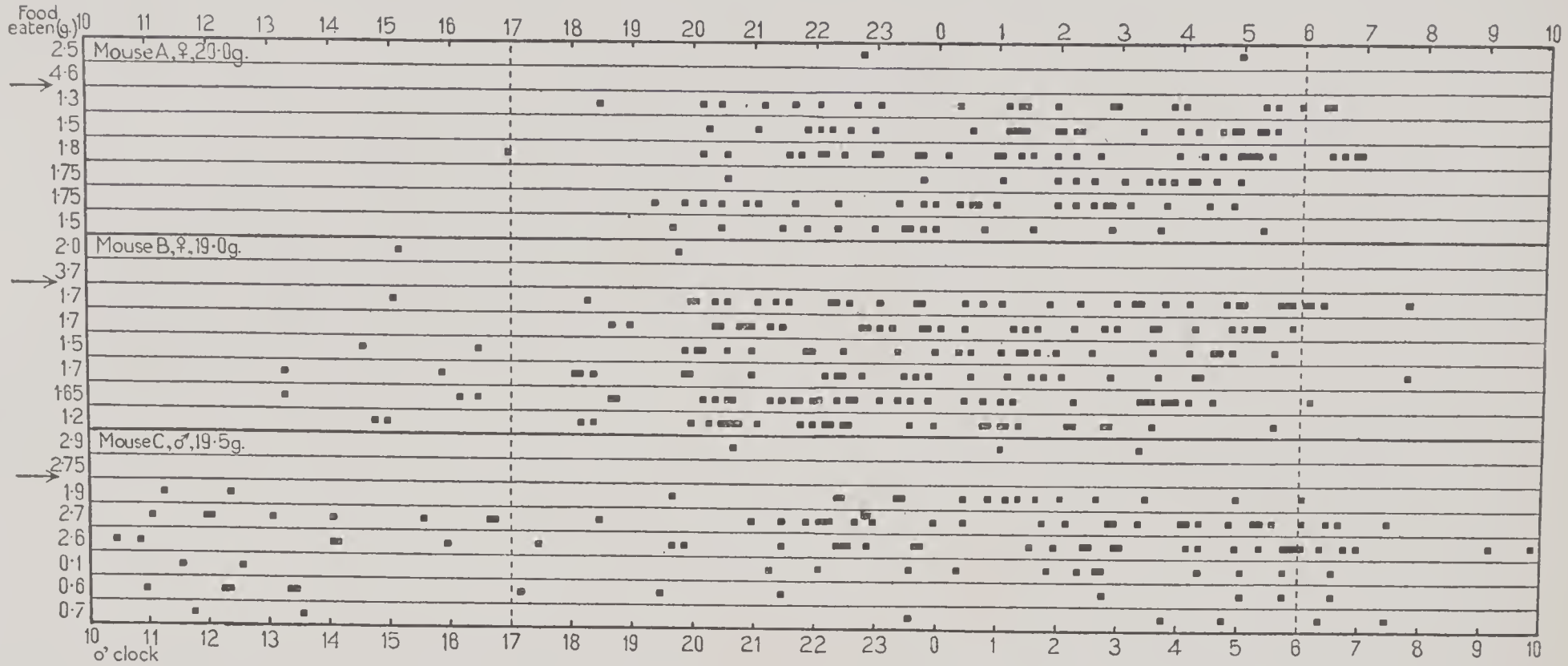


FIG. 9. Feeding activity of three mice for 8 consecutive days in time units of 6 minutes. Interrupted perpendicular lines show hours of darkness. For the first two days wheat was given in tins separate from the recording trays. Similarly food consumption (left-hand column) for the first 2 days is the total amount taken; for the rest only that part (rolled oats) of the total taken from the recording trays.

consumption of rolled oats in competition with wheat is shown. Three facts of major importance emerge from the charts.

(i) The change is immediate and is not spread over several days or even hours. Each mouse shows its characteristic rhythm (notice how these vary in individuals, especially in the amount of day-time feeding) from the first day, which continues unchanged throughout the experiment in the first two cases.

(ii) The feeding rhythm is quite within the normal range of variation we have indicated in earlier sections. The division of interest between two sources of food does not mean that each site is preferred for some hours in turn, but that each is visited concurrently. If Fig. 9 is compared with the previous chart in Fig. 8, we can see that the only effect of dividing interest is a slight tendency to shorten visits. There are not so many periods of continuous attention in Fig. 9. It should have been possible to check this against the charts for the third mouse, which on the fourth and fifth days took practically all its food from the new source, and might be expected to show a normal rhythm and intensity at it. However, this mouse fed a great deal during the day, which means that feeding is not so much concentrated during the night. Even so, the total number of visits during these two nights is rather greater than in the other two mice, who only took about half of their food from the new source.

(iii) A change back to the original food may occur quite suddenly, as shown in the last 3 days' records for the third mouse and in the figures for the weight of rolled oats eaten. Again, it is the suddenness of the change that is interesting, since it confirms the behaviour of all three mice earlier in the experiment. We should also note that the third mouse behaved throughout the test with a great deal less consistency than the other two: it is conceivable that, when a mouse makes an almost complete change to a new site, it is more probable that it will change back again with equal completeness. In any case prebaiting in the field with such behaviour as this to contend with, must necessarily be a difficult business.

(*b*) Slight diversion to new source. This is considered separately from (*a*) because the behaviour concerned is rather different.

(i) Fig. 9 C gives a sufficiently clear picture of what happens, although the period of 'slight diversion' is secondary to an almost complete one. In this case we see that the main decline in feeding activity is during the night feeding time: the sporadic activity during the day changes little, even though the total amount of food taken during the 24 hours may be as small as 0·1 g. Therefore there is a difference in behaviour under heads (*a*) and (*b*), in that a slight diversion tends to be concentrated in the time of day when feeding is most casual. This will have important repercussions on field poison trials, since it will still further reduce the chance of mice eating a lethal dose of bait at a site to which they are not accustomed. The same phenomenon may be observed in the distribution of feeding between three points, all accustomed but one less well patronized than the others. In

Table 25 more visits comparatively are made to the least popular point 3 during the periods before and after the main peak of feeding.

(ii) As under (*a*) however even slight diversion is just as immediate. This is not shown in Fig. 9, but is brought out in several other experiments. In two tests, each with three mice, rolled oats was offered first in tins in the middle of the compartments and then in both these and in the trays connected to the recording machine. Except in the case of one mouse, only a slight diversion was created, and the charts in each instance showed that attention to the new source was mainly confined to the periods before and after the peak of feeding. Furthermore, during several of these daily recordings no detectable amount of food was removed from the feeding tray, yet these had been visited. Presumably these represented 'sample' takes (see Ch. 9) with their consequent danger of producing poison shyness in the mice concerned.

(iii) There is equally a danger of a slight diversion to a new food source being reversed equally quickly, though this is difficult to detect from the weight of food eaten because this was so small. The charts nevertheless show that visits to a new source tend to be more frequent on the first day of its introduction than on subsequent days unless the diversion is a substantial one. This confirms what we have said previously about searching of the environment and interest—often transitory—in any new object (see Ch. 2); experiments on choice between different foods (see Ch. 7) also reveal this passing attention to anything unusual.

12. DIVERSION TO BAITS

The results of these experiments are naturally too slight to foreshadow the reactions of a mouse population, offered a choice between their own food and the baits of the investigator. However, the following figures will give an idea of the kind of variability to be expected. In all these tests of choice between sites eight mice were diverted from the original site only to a very slight extent, while seven were diverted substantially. Of these fifteen animals tested, seven showed a definite reversion back to the original feeding site. From this it might quite well happen in a baiting test that not more than half of the mice would be attracted to the operator's bait points, and some of these would lose interest, if prebaiting was carried on for long.

Some further experiments were made to test the strength and persistence of this attachment to the original and accustomed feeding site. Where a choice had been offered and a marked aversion was shown to feeding at the new site, this latter was left as the sole site for 24 hours and then the choice of sites was offered again. Of five mice tested, three swung over substantially to the new site, while the other two remained as before. Thus even with this extra encouragement (which could of course have no counterpart in natural conditions) the result remained variable.

As mentioned before, choice of two equivalent foods was also tested in

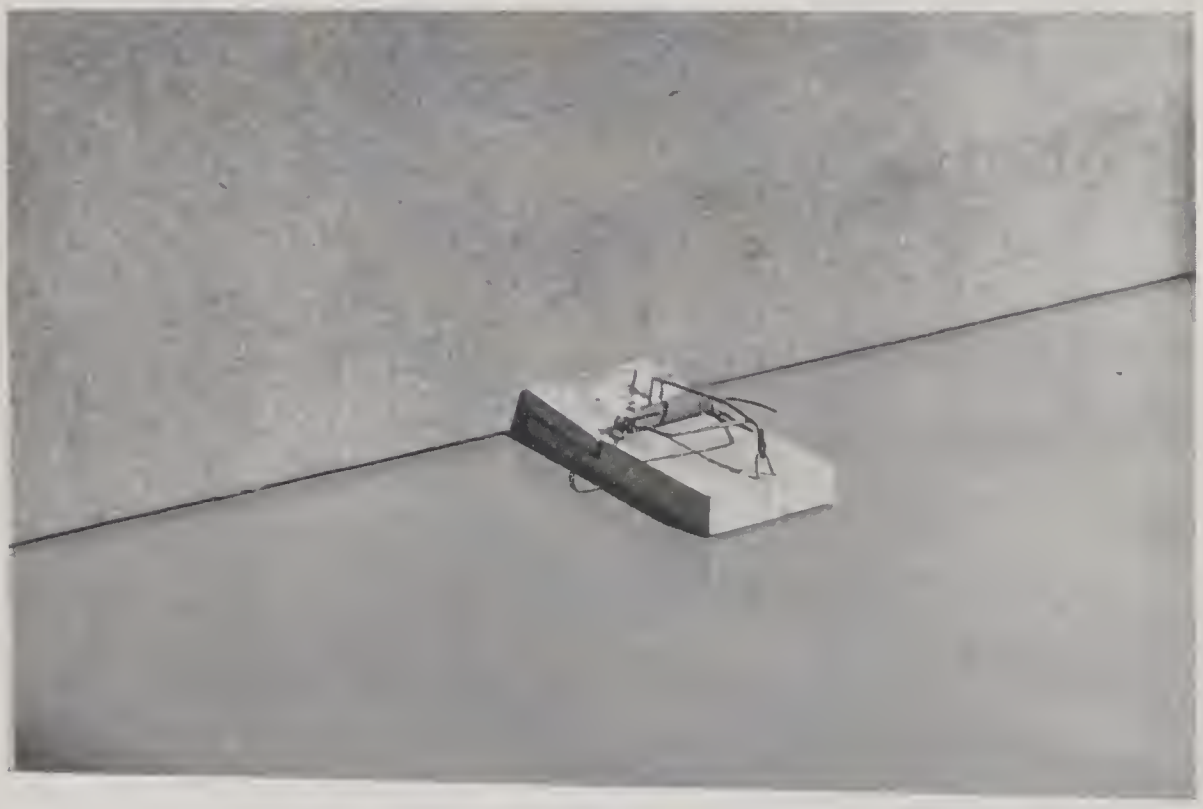
Twelve-month-old oat rick showing the dilapidated appearance after severe mouse damage

PLATE 1

A house-mouse feeding from a bait pile (rolled oats)

PLATE 2

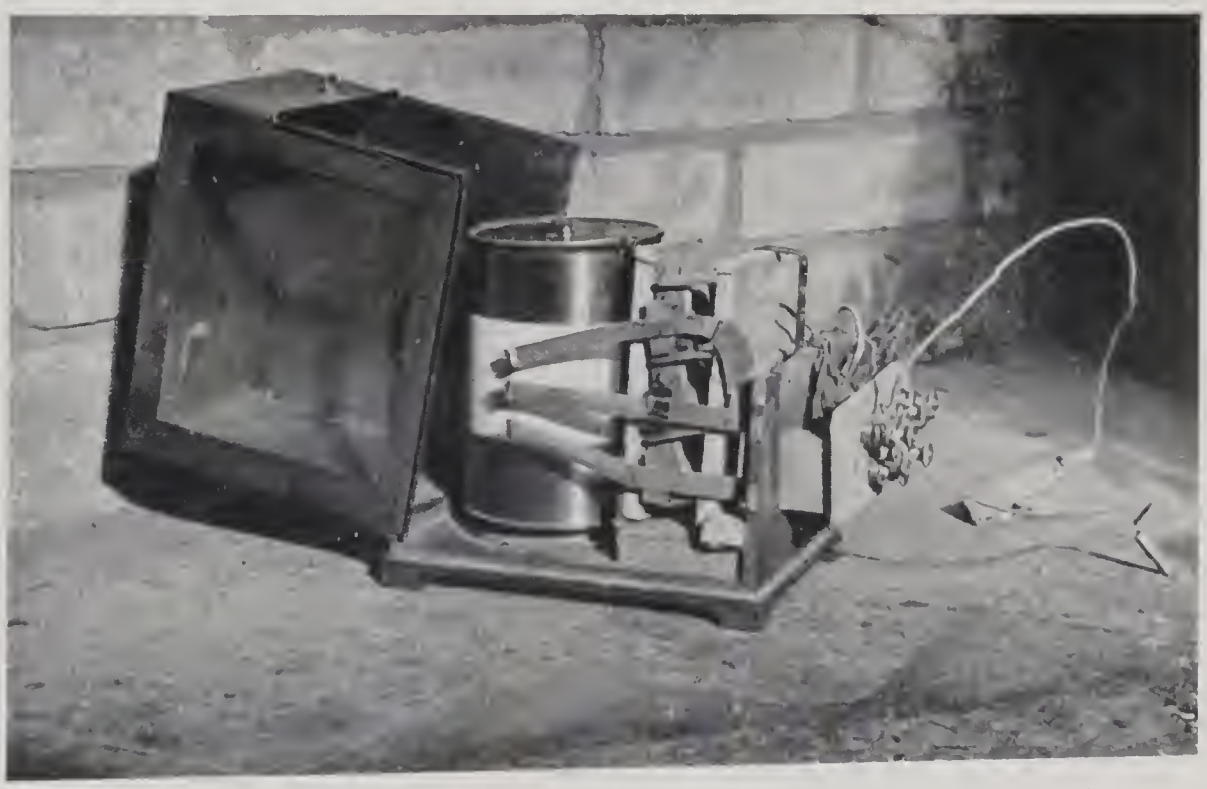
(*a*) Circular glass cage with cover box, zinc lid, and water bottle used for feeding experiments with mice



(*b*) Break-back trap properly set cross-wise to the runway

PLATE 3

(*a*) Tipping food tray with springs and electrical contacts underneath for recording the frequency of feeding



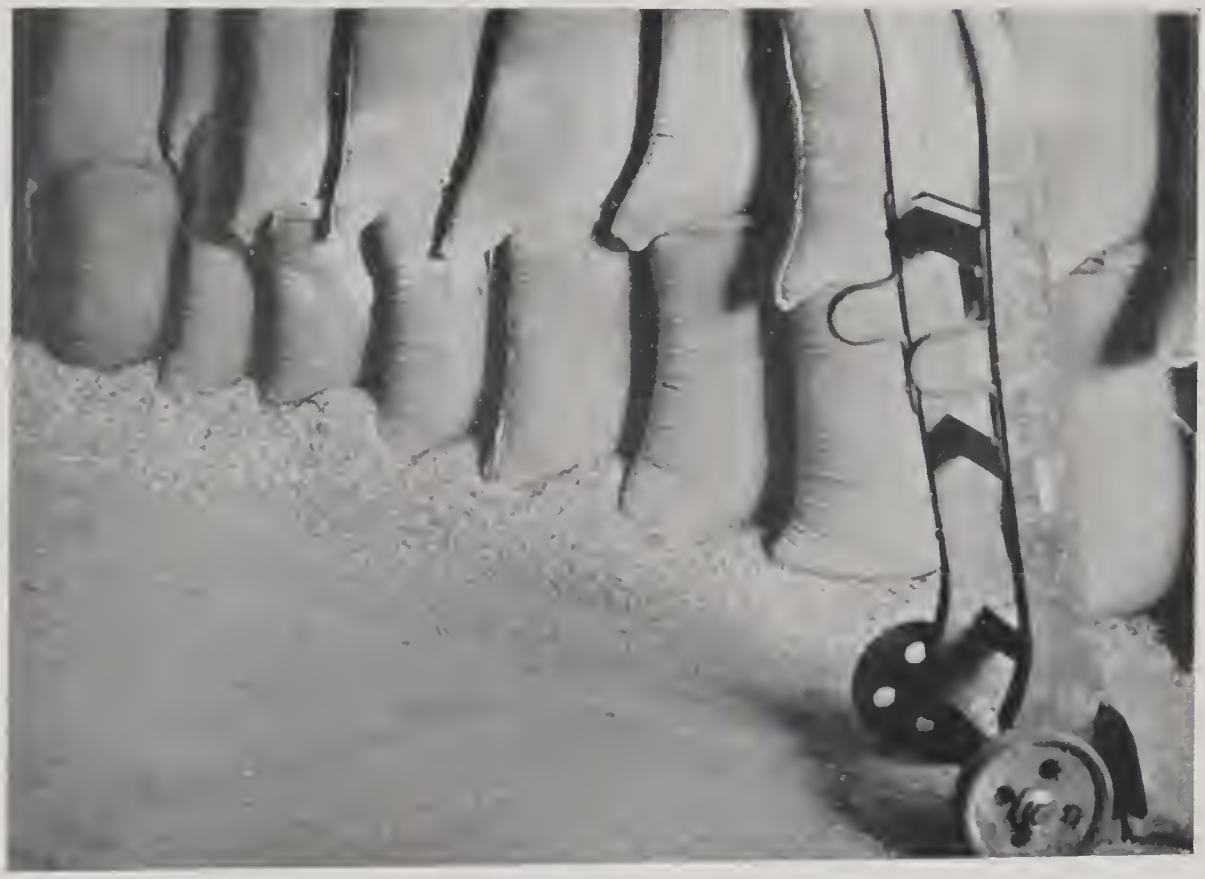
(*b*) Recording drum with pricker arms to record visits to the food trays in three separate cages

PLATE 4

PLATE 5

A house-mouse feeding from a bait tray of flour (taken in the dark by infra-red rays)

(*a*) Typical fragments of grain ('kibblings') left after mice have fed in a store of sacked oats



(*b*) Damaged oats 'bleeding' on to the floor from a pile of sacks

PLATE 6

(*a*) The experimental stack for carbon-dioxide gassing. The cover is rolled back ready for distributing the Drikold

(*b*) The same stack with the cover drawn over and sealed to the ground with weights

PLATE 7

(*a*) A balloon-fabric cover for gassing a small, round rick

(*b*) A larger cover ready to be unfolded over a normal English rick

PLATE 8

these experiments, though we placed most emphasis on the importance of the site. With two equally liked foods, such as rolled oats and wheat, there was no apparent influence on the site choice. Change from rolled oats to wheat or vice versa did not alter the ratio of slight to substantial diversions, which occurred when a choice of sites was offered.

We made several attempts in these experiments to discover whether the position of the new feeding site influenced its attractiveness. In one test we found some slight evidence that if a new site was on the runway from the cover box to the normal feeding tray, more was taken from it than if it had been placed in the middle of the compartment. However, subsequent experiments did not confirm this, and probably a clear-cut result on this matter could not be obtained in such small cages.

The results of this analysis of the behaviour of mice to new food points may be summarized as follows:

1. The addition of a new food site never once succeeded in diverting the whole attention of a mouse to it.
2. About half of the mice tested paid some attention to the new site (up to half of their daily consumption); the others paid slight attention to it.
3. Where patronage was slight, it was principally confined to the hours outside the main feeding peak.
4. Such diversion of attention was not necessarily permanent. Mice were as likely as not to swing back again to the original site.

These results must influence the planning of baiting techniques to be used in the field. We showed earlier in this chapter (pp. 89–90) that even when a mouse is feeding from one site only, its feeding behaviour is such that only a small amount of poison may be taken before warning symptoms arise. Where there is the added complication of the mice being attached to their normal food supply, so that the operator's baits receive only slight favour, we are even less likely to succeed in poisoning a whole population. Finally, in the comparatively large part of a population, whose attention is only slightly diverted to the operator's baits, feeding is mainly confined to the period of sporadic activity before and after the main peak. This probably means visiting and taking samples only of the food offered (sometimes in quantities less than 0·01 g.), with the almost inevitable result that this part of the population becomes shy of approaching further poison baits.

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7

THE FOODS THAT MICE PREFER AND THE WAY IN WHICH THEY EAT THEM

In the last chapter we considered the general feeding behaviour of house mice as analysed in the laboratory and the variable results of offering them choices between feeding sites. This chapter deals first with food preferences in house mice and the influence upon them of broad differences in environments, so that we can be sure in the first place of having a number of attractive baits to offer. After that we discuss the practical application of this knowledge about preferences and feeding habits to field baiting.

1. LABORATORY EXPERIMENTS ON FOOD PREFERENCES

Field experiments on food preferences are difficult to interpret because so many environmental factors may be influencing them, and so the results obtained in the laboratory are here described first and field experiences discussed afterwards in their light. In the laboratory environmental factors, except those intentionally varied, were constant, so that the basic behaviour of the mice in choosing between different foods could be elucidated.

All the experiments described except one were carried out in a cellar at the Oxford University Museum, where cages containing stocks of voles were housed. Wild house mice, obtained from corn-ricks at threshing, were released, supplied with their own source of food, and allowed to settle down.

We adjusted the numbers of mice so that there should be no adverse effect on the experiments, which consisted of giving choices of various foods according to an arranged scheme. Too few mice would expose the results to error owing to the effect of individual preferences among them: too many, on the other hand, might bias the proportions of foods taken by overcrowding at the feeding boxes.

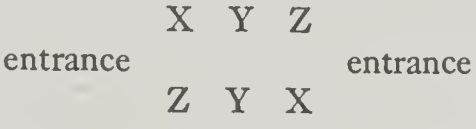
Therefore on an area this size (floor space 264 sq. ft.) we maintained the population at a level of 12–20 mice.

The cellar was artificially lit by two 75-watt bulbs, which were controlled by a time switch, going off at 8 p.m. and on at 7 a.m. One or two visits lasting 15–30 minutes were all that disturbed the mice each day.

The experiments lasted from November 1942 to May 1943, and during practically all this time the cellar was artificially heated, the temperature ranging from 16–21° C. and the relative humidity around 40%.

The procedure was as follows. Two jars of food were placed one at each end of the cellar and the consumption measured daily for a week or more to ensure that a steady amount was being taken. Then two choice boxes were substituted, each measuring 12×9×6 in. with entrances at each end and

the top covered with wire netting. Inside each box the choice of foods was arranged as shown in the accompanying diagram. Tins of exactly similar size and appearance were provided for each food and these were moved about in rotation every day, so that the same arrangement of foods only recurred once in 6 days. The mice were not at all shy of these choice boxes, and the weight of food eaten on the first choice night was usually about the same as on the last night of preliminary feeding.



We weighed the food remaining every morning at 10 a.m., using a spring balance, accurate to the nearest 0·1 g. Exceptionally some was spilled in the box and had to be distinguished and collected for weighing; none was ever spilled outside the box.

In Figs. 10–14, the results of these experiments are expressed in percentages. The actual amounts eaten each night are given in an appendix from which we see that the range was 25–100 g. These limits represent approximately 8–20 mice.

We used two boxes primarily to prevent overcrowding at the food tins, but the arrangement also served to check whether in groups of such a size individual feeding behaviour influenced the general trend of the preferences shown. In some cases reactions at one box were slower than at the other, but in every case the general patterns of the results were identical. Two boxes also enabled each test to be started with different arrangements of the food.

Experiment 1 (Fig. 10) was designed to throw light on the effect of habituation on mouse feeding preferences. It fell into three phases (marked *A*, *B*, and *C* in the figure) in each of which the mice were conditioned to a different food before being offered a choice. The three foods used were rolled oats, plain national flour (wheatmeal), and breadcrumbs broken up small from stale bread.

In *A* the mice were given national flour only to eat for 7 days, and then we put down the choice boxes. The results are very interesting. At the beginning the mice preferred rolled oats, but after the first day they abandoned it fairly rapidly until finally they were eating 75% of national flour, the food to which they had been conditioned. Breadcrumbs they clearly disliked, though they ate small amounts during the first 2 days.

In *B* the mice had rolled oats only to eat for 10 days before the choice test. The figure shows that they hesitated a long time before they established a preference for the food to which they had been accustomed; even then the preference was not so strongly marked as in A. Again after a short sample to begin with the mice refused breadcrumbs.

In *C* exactly the same procedure was followed: the mice were conditioned

for 12 days to breadcrumbs, which they were compelled to eat at the same rate as the other foods. The figure shows that no very clear preference was given to any one of the three foods, but increased interest in the breadcrumbs owing to the conditioning contrasted most strikingly with what happened in *A* and *B*. In fact, at the end of the 6 days the mice were eating breadcrumbs in greater quantities (though only just so) than either of the other two foods. Again, as in *A*, the mice started with a preference for a food different from that to which they had been habituated.

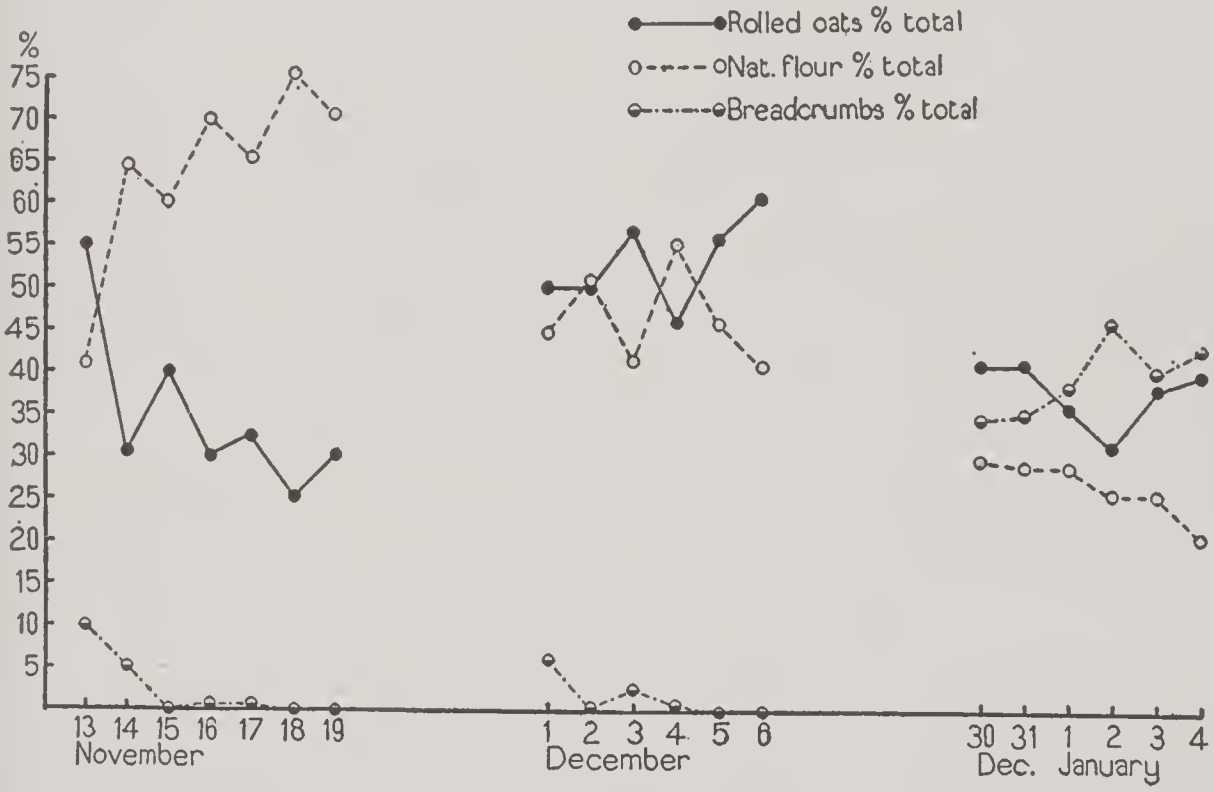


FIG. 10. Food choice of mice after conditioning. (Phases A, B and C from left to right.)

This experiment shows three main results. In the first place, the effect of conditioning is quite clear; if other things are equal, mice will prefer the food to which they have been accustomed. This fact will obviously affect how we choose and lay baits in the field.

Secondly, this preference asserts itself at different speeds. In both *A* and *C* the food finally chosen was not the one preferred on the first day; in *B*, although rolled oats was leading both at the start and at the finish the figure shows a very hesitating course in between. This again is an important point for planning field trials.

Thirdly, the difference in the course of events in *A*, *B*, and *C* shows that, conditioning apart, there is probably an absolute order of preference between the three foods in these circumstances. The order is probably national flour, rolled oats, and breadcrumbs; so that we must allow for basic preferences as well as the conditioning effect of available foods. This is important in field trials where there is no time to test the bait preference of the population beforehand.

Experiments 2, 3, and 4 (Figs. 11–13) were designed in order to test this basic order of preference more fully. We hoped to find a food which was so palatable to house mice that the effect of conditioning would be overcome. Although this aim was not wholly fulfilled, the results are nevertheless interesting.

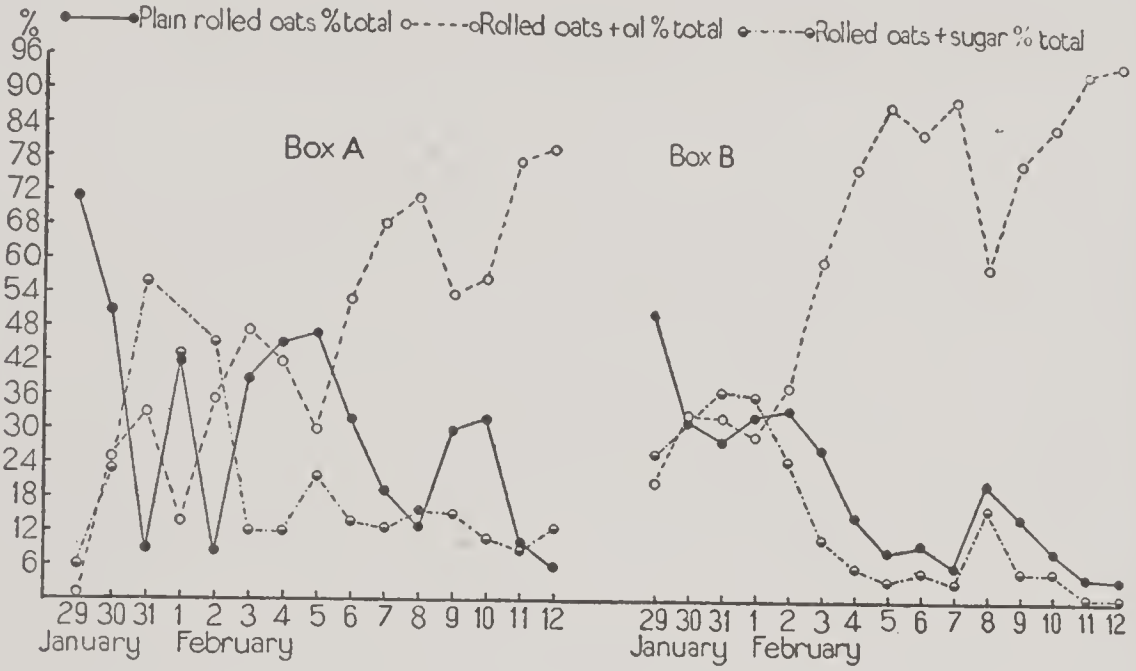


FIG. 11. Food preference of house mice between rolled oats plain and mixed with sugar or oil.

A choice experiment between rolled oats, soya flour, and a half-and-half mixture of the two revealed so strong an aversion to the soya flour, plain or diluted, that it is not worth describing in detail. The one point of interest is that, as in the first experiment, a small 'sample' of it was eaten on the first day.

After this a series of experiments (2, 3, and 4) was carried out to test whether house mice preferred their rolled oats mixed with oil. Generally speaking making up baits in a fatty base, a procedure much publicized by some authorities, does not seem to be attractive to mice. Some tests were made with various foods mixed with a fat that set hard, such as whale oil, paraffin wax, and coco-nut oil, so as to provide a bait with permanent keeping qualities, but mice either disregarded them or took only small quantities. A liquid oil, however, is a different matter. In Fig. 11 is shown the result of offering to mice, which had been living on rolled oats, a choice of rolled oats plain, the same mixed with 10% castor sugar, and the same mixed with 10% olive oil. The results at the two boxes show practically the same trends: an initial preference for plain rolled oats, a change to rolled oats with sugar, and then finally a strong preference for rolled oats with oil. However, the mice visiting box A took longer to make up their minds, and even at the end of the experiment the final preference was not

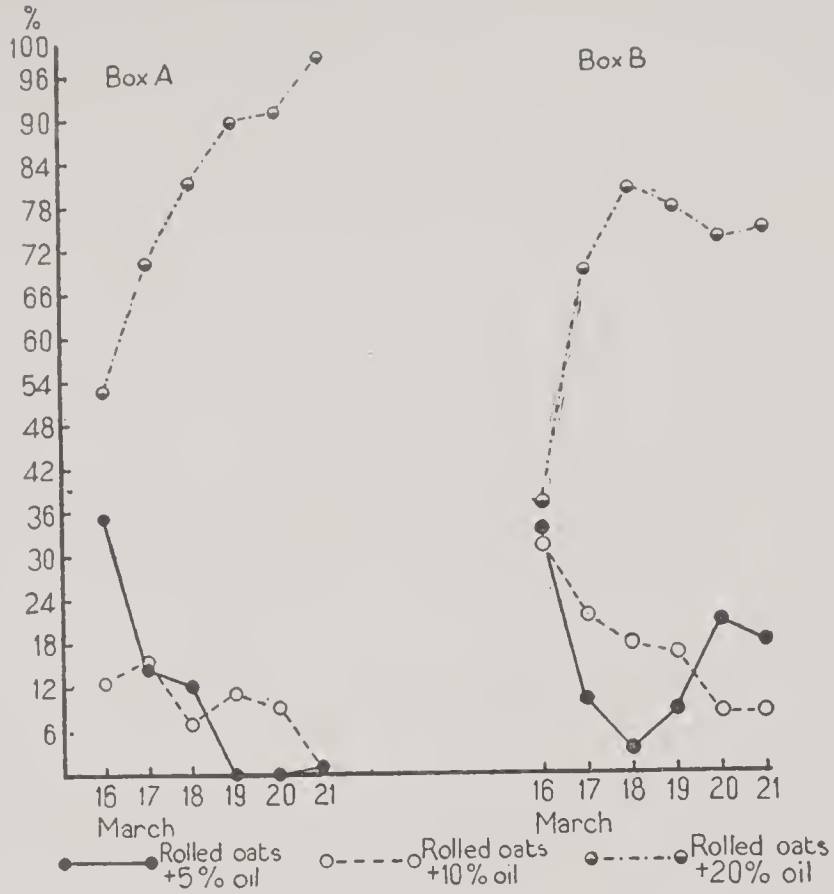


FIG. 12. Food preference of house mice between rolled oats with three different percentages of oil.

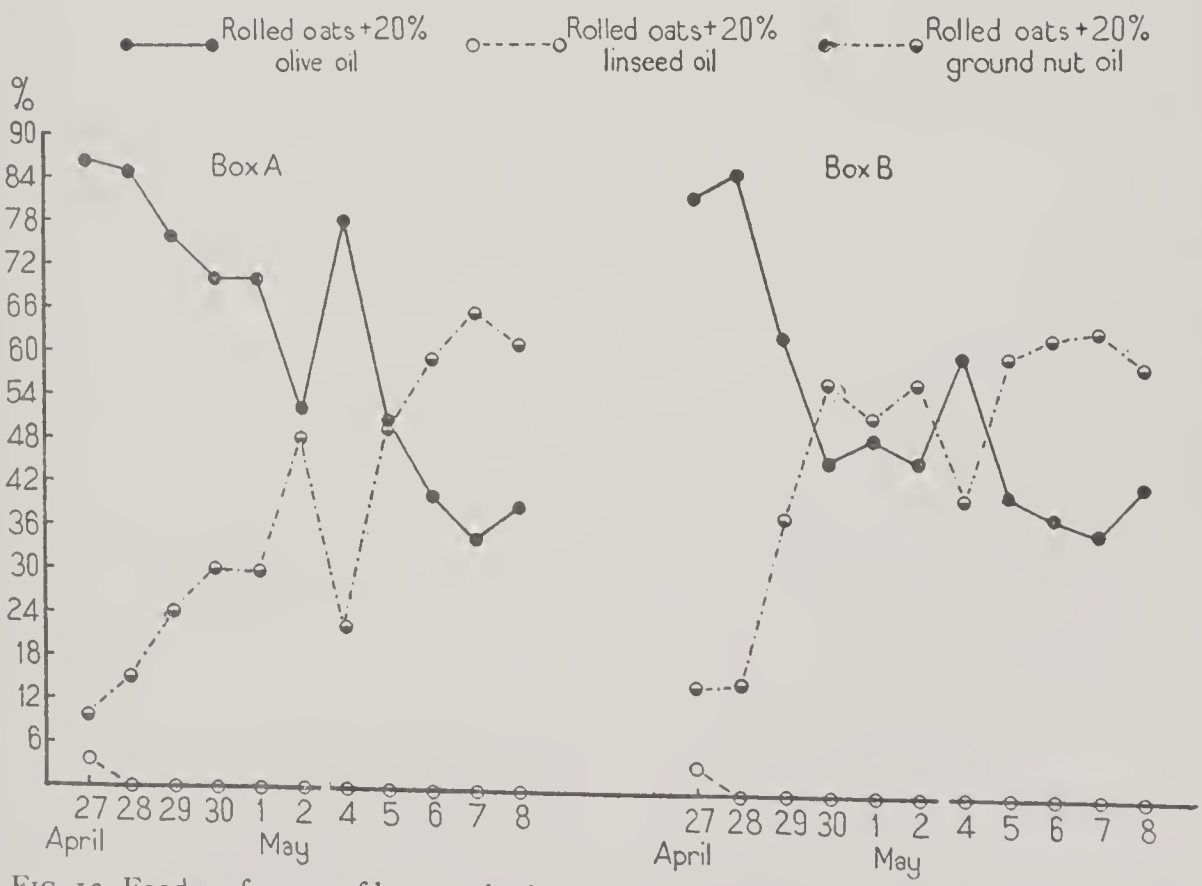


FIG. 13. Food preference of house mice between rolled oats mixed with three different oils,

quite so pronounced as in box B. This is no doubt due to the effect of individual preferences not being quite the same in the two groups.

Fig. 12 shows a further experiment in which the preference for different percentages of olive oil was tested. The result is very clear-cut right from the beginning, the preference being so overwhelming that there is no period of temporary preference for either of the other two choices, nor a subsequent period of indecision.

Lastly, Fig. 13 compares the relative palatability of various oils mixed with rolled oats. The purpose of this experiment was to determine whether another oil, more easily obtainable than olive oil, could be used in its place. The initial preference for olive oil is very marked, but eventually groundnut oil came to be preferred after a rather long period of indecision (at any rate in box 2). The result with linseed oil is uncompromising, though here again the preliminary interest is shown which appeared in most of the previous experiments.

The result of all these experiments was that rolled oats mixed with 20% oil was tested in a number of field trials. The results are discussed later in this chapter. They were patchy, being even more successful than we had hoped in one or two tests, but distinctly disappointing in others. The difference is probably due to the environments whose influences we had hoped to overcome by finding a particularly palatable bait.

Experiment 5 (Fig. 14). This was carried out by Miss Laurie to test the effect of temperature and the presence of drinking water on the choice between moist and dry baits. The foods she used were dry rolled oats and moist sausage-rusk (mixed with an equal part of water). The determination of the consumption of sausage-rusk was made by drying the residue, weighing this, and adding 10%, which is the original moisture content of the dry rusk. The consumption is then expressed in terms of dry weight (see also Ch. 3). The mice were released in a wooden outdoor shed, which reflected outside temperatures with little or no lag and two feeding points were used. Water was offered in open trays.

During the first phase of the experiment, when no water was provided, the weather changed from moderately cool to very warm, and the mice showed a very strong preference for the moist bait, although at the beginning they only ate a small amount.

There are probably three factors involved in this rise: habituation to the bait, increase in temperature, and lack of water supply (relative to needs). It is impossible to disentangle the effect of each, but the last two will be linked together in most habitats and are probably the most important.

After 26 July water was given, but the temperature remained about the same. There was a decided drop in the amount of moist bait eaten, which was almost certainly due to one factor only, the new supply of water. The slight increase at the end of the experiment, when the weather became very warm, may perhaps be significant.

The presence or absence of water, therefore, has a distinct influence on the choice between a dry and a moist bait, and this effect is accentuated in high temperatures. From this result we may expect that in certain habitats, where water is scarce, e.g. corn-ricks and some food stores, mice will eat a moist bait much more readily than a dry one. In such circumstances adding

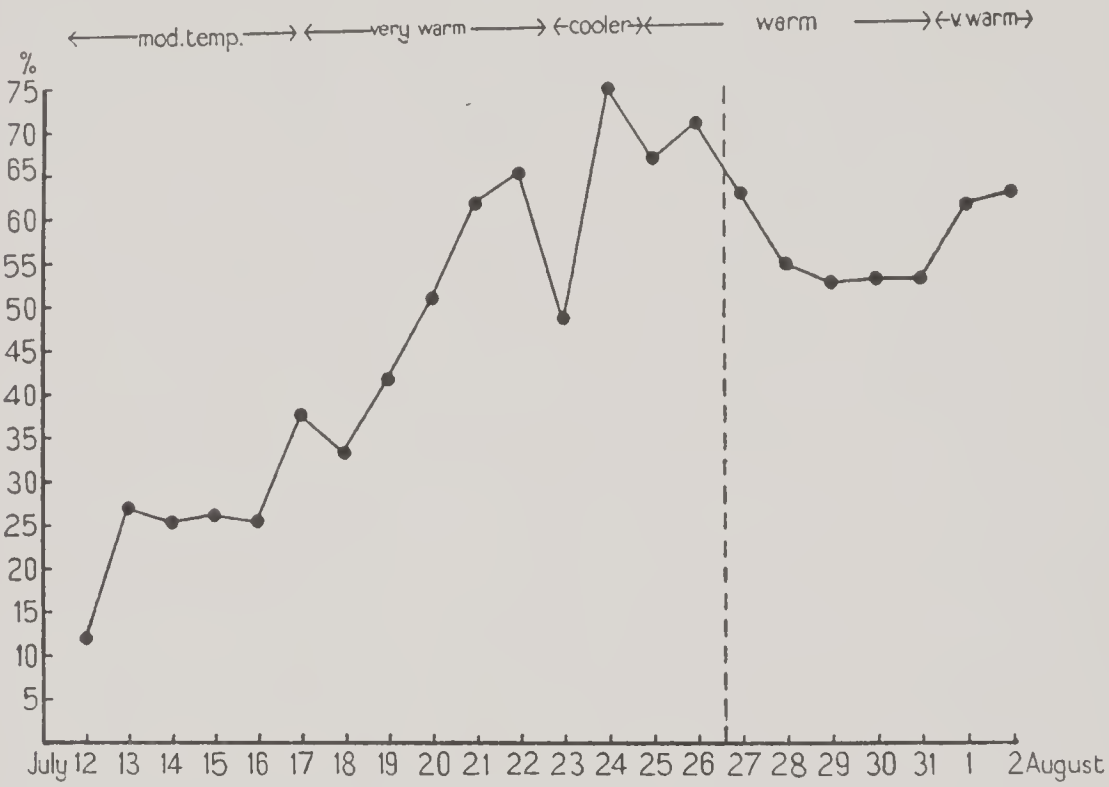


FIG. 14. Food preference of house mice between dry rolled oats and moist sausage-rusk, expressed as a percentage of the latter (dry weight) in each day's consumption. Weather is noted at the head of the figure and from 27 July onward a supply of drinking water was provided.

water should increase the palatability of the bait, so that the preference for it should override the conditioning of the previous diet.

2. FIELD EXPERIMENTS ON FOOD PREFERENCES

Table 29 summarizes the most important data that were obtained in field experiments. Most of the choice tests were done as preliminaries to pre-baiting and consisted of offering a choice of baits side by side to discover which was preferred. In some experiments we offered different baits one at a time, and since in these cases we were putting down surplus baits the comparison, although not between baits offered simultaneously, should be valid because of the larger size of the figures. Notes are also included in the table on whether the total amount of bait eaten each day decreased which would suggest a return to the accustomed food.

Dryness of the environment. The first twelve experiments (with the exception of No. 8, which formed a special case and is discussed separately) may be compared as a whole with the last five because they show that the mice

were willing to take dry baits. In experiments 13–17, however, the choice mostly favoured moist baits. The broad conclusion is that in dry environments (these include places where water is present, but distant from the main inhabited area, cf. remarks in Ch. 2 on range of house mice) moist bait will almost certainly be taken better (in some cases far better) than dry bait. It is worth analysing the environments in which the various experiments were done a little more closely in order to bring this out.

TABLE 29. *Bait choice experiments carried out in different environments in the field*

No.	*Date*	*Choice offered and result*	*Locality and environment*
1*	24 Oct. 1940	Lentils, split peas, 3 grades of rice, rolled oats, and oatmeal. All taken except first two	Grocer's store; no heating; all kinds of food present. Moderate sized population
2*	11 Nov. 1940	Canary seed, hemp, Phalaris, yellow and white millet, linseed, and poppy. None eaten	Saddler's store adjacent to 1. No heating; dog biscuits only, but mice may have visited from next door. Small population
3	12 Oct. 1942	Flour and rolled oats. Both taken equally well	Restaurant and storerooms. Heating, but plenty of water; all kinds of food; large population
4	12 Oct. 1942	Flour and rolled oats. Latter greatly preferred	Same grocer's store as 1. Small population
5	17 Apr. 1944	Flour and rolled oats given consecutively. Both taken in same amounts	Grocer's and greengrocer's shop. Heated during the day; plenty of wet food; all kinds of dry food. Fairly large population
6	17 Apr. 1944	Rolled oats, plain and oiled. First preferred, more distinctly at the start of the test than at the end	Same as above.
7	11 Feb. 1943	Rolled oats, plain and oiled. Latter slightly preferred during choice test; slight drop in take when used alone afterwards	Wholesale grocery store. Heated, but not very warm. Food of all kinds, but scattered; mice living mostly on custard powder. Small population
8	Sept.–Nov. 1943	Rolled oats, s.r.m.+sugar, r.o.m.+sugar. See discussion	Oxford market. See discussion
9	5 Feb. 1943	Rolled oats, plain and oiled. Latter preferred, but take dropped to zero afterwards	Basement of Pathology Dept. Very warm. Little food except occasional scraps; probably not much water. Small population
10	22 Feb. 1943	Rolled oats, plain and oiled. Both taken equally. Slight drop in take during prebaiting	Theatre dressing rooms. Warm; plenty of food scraps. Small population
11	5 May 1944	Rolled oats, plain and oiled. Former much preferred	Basement of Pharmacology Dept. Warm; main food rat cubes, but kitchen refuse also present. Probably plenty of water. Large population

TABLE 29 (*cont.*)

No.	*Date*	*Choice offered and result*	*Locality and environment*
12†	2 May 1943	Rolled oats, plain and oiled, flour. Choice: 2, 3, 1	Electrical equipment factory. Heated; probably not much water; food scraps only. Large population
13	July–Aug. 1943	Rolled oats, plain and oiled, and s.r.m. offered consecutively. Last much preferred	Stacks of sacked oats in a food store. No heating; water scarce, food whole oats. Fairly large population
14	21 Oct. 1943	S.r.m. with and without sugar. Both taken well at first, but former fell off afterwards	Food store as in 13
15†	23 Mar. 1944	Oatmeal, flour+sugar, and s.r.m. Choice: 2, 3, 1	Food store. No heating. Water probably scarce; only food broken Welfare biscuits. Fairly large population
16	Summer 1943	Various dry baits and s.r.m.+zinc phosphide in corn-ricks. See discussion	Many experiments on corn-ricks. See discussion for results
17	Winter 1943–4	Rolled oats, s.r.m., r.o.m., and flour paste in various sequences and combinations. See discussion	Many experiments on stacks of bagged oats and flour. See discussion for results

s.r.m. = sausage-rusk mash; r.o.m. = rolled oats mash.
* Experiments marked thus were done by C. Elton.
† Experiments marked thus were done by J. Watson.

TABLE 30. *Analysis of types of environment according to presence of water*

Type of environment	*No. of experiment*															
Plenty of water .	..	..	3	..	5	6	..	..	..	11	..	..	..	..	..	..
Moderate amount of water . .	1	2	..	4	..	..	7	..	..	..	..	..	..	..	..	..
Little water or food	..	..	..	..	..	..	..	9	10	..	12	..	..	15	..	..
Little water, food plentiful . .	..	..	..	..	..	..	..	..	..	..	..	13*	14*	..	16*	17*

* In these cases a dry bait was definitely disliked.

From Table 30 it will be seen that the only type of environment in which dry baits were definitely avoided (even in the absence of other kinds of bait) are those in which water is scarce and food abundant. Such conditions are found most frequently in food stores and corn-ricks, and it is clear that as a general rule it is no use offering dry bait in such circumstances. On the other hand, the third class of environment in Table 30 shows that sometimes dry bait may be taken where water is scarce, but this nearly always means that food also is scarce and the mice are hungry. These conditions

apply to a certain number of domestic premises, to factories, and other large buildings, where the food supply consists mainly of employees' meal scraps, and to food stores, where the goods are in boxes or tins, or otherwise unsuitable, e.g. in experiment 15, where there were only hard 'Welfare' biscuits to eat.

Experiments 1, 2, 4, and 7, which we have entered under the heading 'moderate water supply' are not quite as clear as they might be, since they were carried out in 1940 and 1942 before we began to use moist baits. It is possible in these instances that a moist bait might have been preferred. There is no doubt, however, that some water was available because the storerooms were small, there were wash rooms, &c., on the top floor and rain drove into the house in a number of places. It is probable that the argument is still sound. Collateral evidence on this point is contained in the discussion of experiment 8 (q.v.).

We can conclude that where food is scarce mice will take almost any cereal bait, whether water is present or no. In the presence of food the water supply becomes important, and in dry environments a moist bait is best.

Choice of dry baits. In general it is clear that cereal baits are the ones most preferred. Experiments 1 and 2 carried out by Elton in a grocer's store where there was an abundance of all kinds of food, showed that only cereals were eaten, when he offered choices between these and legumes and other kinds of seeds. Mice dislike legumes even when other food is scarce, since a stack of bagged vetch seeds in an Oxford food store remained unharmed even when all other food was cleared out of the premises.

The choice tests 1–7 and 9–12 mostly involved national flour and rolled oats with or without 20% of oil, since the laboratory experiments had shown that these were the most promising baits to use. The results in the field are contradictory. Of four experiments (3, 4, 5, and 12) in which plain rolled oats and flour were tested against one another, two showed no definite preference and the other two showed a preference for rolled oats. Of six experiments (6, 7, 9, 10, 11, and 12) in which rolled oats with and without oil were tested, one showed no particular preference, three showed a definite preference for oiled rolled oats, and two showed a definite preference for plain. There was no obvious connexion between the choices and the type of environment.

The answer must, therefore, be either that individual preferences have biased the results, or that mouse populations show variation in choice either absolutely or in relation to some unidentified environmental factor.

Individual preference is clearly seen in some instances. Two small-scale experiments were carried out on domestic infestations involving only one or two mice in each case. In one dry rolled oats was eaten and bread and milk disregarded; in the other the exact opposite occurred. However, it is likely that in larger populations such individual preferences would cancel out in the way shown by using two choice boxes in the laboratory experiments.

The second answer is probably the correct one, but it is impossible to determine from these data whether the variation in choice is related to some unknown factor in the environment or no. Conditioning would, as shown by the laboratory experiments, produce such results, but cannot be proved here.

The practical importance of these experiments is clear. Wherever possible, a choice test should precede prebaiting because except on broad lines (e.g. when it is a question of moist or dry bait) the most likely bait to be eaten cannot be predicted.

Decline in amount of prebait eaten. Three instances are shown in Table 29 (experiments 7, 9, and 10), where baiting with the preferred food was continued for about a week before poisoning. Every time the amount of prebait taken increased to a peak in about 5 days and then fell slightly on subsequent days. As explained later in this chapter in the section of prebaiting, this peak is probably a 'false' one since it is not caused by drawing mice to feed more and more upon the bait as happens with rats. In fact there is evidence that, if the bait is distributed properly and is available to all the mice right from the start, they may begin to feed straight away at 'peak level'. This did occur in some of the baiting experiments in food stores (see Table 40). The decline is nevertheless significant, indicating that the mice have to some extent lost interest in the bait.

These three examples reveal a phenomenon which has been encountered many times in poison trials against house mice. In view of the results from laboratory experiments it does seem probable that the cause may be the fading-out of an initial attraction to a new food. This is important because it means that prebaiting should not be continued for too long with mice: thus, very liberal baiting on the first day to make sure that bait is brought to the attention of all accessible mice, then a quick increase on the following day at points which have been cleared, and finally poisoning within 3 or 4 days is probably the best sequence to adopt.

Absolute preference for baits. This refers to preferences due to inherent qualities in the bait and not to associations or physical conditions (e.g. lack of water). Obviously some foods are liked more than others by mice for their own sakes, as shown in the laboratory experiments on choice, and the most important result of all the field experiments has been to show that, as a general rule, rolled oats is the best general purpose bait for house mice. Where there is no time to do a choice test, this is the bait most likely to succeed.

Outside the laboratory it is difficult to say when a food is preferred for its own sake and not because of conditioning. Two experiments on corn-ricks, which are described fully in Chapter 12, show a clear instance of absolute preference and that rather a curious one.

Two wheat ricks of the same size, from the same crop, and containing approximately the same number of mice were poisoned, the one with 5%

zinc phosphide, the other with 10% arsenious oxide, both in moist sausage-rusk (1 part rusk to 1 part water). In the rick treated with zinc phosphide 70% of the mice were killed and very little bait picked up at threshing; in the one treated with arsenic 15% only of the mice were killed and quite a lot of bait picked up. There seems no alternative to supposing that the mice preferred the taste of zinc phosphide, a taste that could not have been associated with anything in the mice's experience.

The Oxford market. We carried out a large-scale poisoning test here from September to November 1943. This area contained such a medley of environments that the evidence obtained about preference is bound to be interesting. At the same time results are inevitably obscured by difficulties of laying bait methodically, where the shopkeepers differed so much in their welcome to us.

We started baiting in all the premises (twenty in number) with small piles of dry rolled oats. These were taken well in practically all the shops, no matter what their contents, a result which substantiates the general preference for this bait mentioned above. We poisoned first with red squill extract and so the prebait had to be changed to a moist one. Sausage-rusk mash was used and the results of this change were very variable, and in some of the shops there was a distinct reduction in the bait eaten. The distribution of these reductions according to the kind of shop concerned is shown in Table 31.

TABLE 31. *Drop in take at the change from rolled oats to sausage-rusk mash according to the type of premises*

Greengrocers	2/6
Firewatchers' premises (living on scraps) .	1/1
Grocers, Confectioners	1/5
Butchers	4/7
Total	8/19

From this table we see that butchers' shops head the list, followed by greengrocers'. In these water would be plentiful and would account for the distaste for wet bait. This would not, however, account for the mice eating less moist bait at one grocer's premises; possibly here they were habituated to cereal foods. The firewatchers' premises had plentiful water because they were next door to a fishmonger's.

However, there were other greengrocers' and butchers' shops where no such reduction occurred, so that the presence of water could not have been the only influence. Without doubt the behaviour of the mice must have been partly caused by individual preferences of populations.

Under the circumstances another moist bait had to be found and a mash was made by mixing rolled oats with 25% of its weight of water. This was readily taken, but is unfortunately not a good bait on account of its stickiness.

The whole history of this prebaiting, though it throws some valuable

light on the effects of water supply and conditioning, shows that the most important thing is to use a generally preferred bait except in the rare cases (in these types of environment) where it fails in a choice test.

A final point of interest was the way in which at two places mice at one end of a room refused to take sausage-rusk mash, but took it continuously at the other end. Presumably we are getting down here to populations small enough to betray individual preferences.

Experiments in food stores. During the winter of 1943–4 a number of experiments were carried out by Rżóska and Southern in a M.O.F. buffer depot near Oxford, which contained many stacks of white flour and five of sacked oats. All these stacks covered a large area (several hundred sq. ft.), but the oats were stacked only three sacks high. Most of the mice were living inside the stacks and we could only bait round the outsides. The procedure we adopted was to put small amounts of plain bait (*c.* 2·5 g. of dry rolled oats and *c.* 3 g. of moist sausage-rusk) both at ground and at head level into the side of the stack being treated. The consumption was reckoned in points cleared or partly cleared during each 24 hours.

In the first set of experiments we baited an oat stack and a flour stack with dry rolled oats for about a week, during which the amounts taken were very small, and then we made a change to moist sausage-rusk. The figures in Table 32 illustrate how steeply the figures jumped upwards.

TABLE 32. *Effect of changing from dry to moist bait in a food store*

Day	*Bait*	*No. of points cleared in flour stack*	*No. of points cleared in oats stack*
1	Dry rolled oats	2/66	4/24
2	,,		5/24
3	,,	2/66	0/24
4	,,		
5	,,		0/24
6	Sausage-rusk mash	18/66	24/26
7	,,		32/34
8	,,	36/66	
9	,,		33/34
10	,,		..

N.B.—Brackets indicate takes summed, not averaged.

After these preliminary results all subsequent experiments were done with moist bait. Most of these were designed to discover the choice of baits after poisoning and are dealt with in Chapter 9. However, we may pick upon one or two significant points here.

An experiment was carried out on two oat stacks, one of which was baited with plain sausage-rusk mash, the other with the same with 10% castor sugar added. Bait consumption in the first stack stayed at a high level (over 70 out of the 100 points placed for 3 consecutive days), whereas in the other, in which sugar was mixed with the bait, the take rose to a peak of 45/50 and

declined during the next 4 days to 26/50. There is little doubt from this result that the mice were growing tired of the bait and went back to their original food.

In the other experiments the baits used were sausage-rusk mash, rolled oats mash, and flour paste. There was no distinct preference between the first two, and changes from one to the other could be made without altering the general level of consumption. Flour paste, however, was disdained and we abandoned it after one trial.

Conclusions. The information gathered in the above field trials partly confirms and partly extends the results from the laboratory experiments. The conclusions may be conveniently compared with those from the latter and summarized as follows.

(*a*) *Absolute preference.* By this we mean the actual palatability of the various baits to mice as far as that can be disentangled from environmental factors influencing the choice. In the laboratory experiments the mice clearly preferred rolled oats with 20% oil, but, since the results of using this bait in field trials were contradictory, it is probable that some unknown environmental factor was responsible for the unanimous choice in the laboratory. On the other hand, the variations of choice in the field may have been due to differing tastes of different populations. The result of experiment 1, which suggested an absolute preference for national flour over rolled oats, is similarly not confirmed by field tests.

The general conclusion we can draw about absolute preference is that it can only be determined in a broad way, and attempts to analyse it more closely break down because of factors of environment or habituation that may enter into the problem. From the results of all the experiments described we cannot doubt that dry rolled oats is the most acceptable bait for mice, but there are occasions when other baits have to be used instead.

(*b*) *Individual choice.* The experiments described above contain abundant evidence to illustrate how small populations may differ in bait choice even between one side of a room and the other. The field trials in the Oxford market show this effect more clearly than the laboratory experiments. Naturally the importance of this factor will be in inverse proportion to the size of the population.

(*c*) *Effect of environmental factors.* It is rather difficult to separate conclusions under this head from those under the next, since conditioning to certain foods is to some extent due to the environment. However, certain choices are more directly due to physical or physiological factors, and this is most clear over the question of water supply and temperature. Where a fairly dry food is being eaten and the supply of water is absent or difficult to reach, a moist bait is always taken better than a dry one. Other environmental factors, such as those affecting the balance of the diet (see Chs. 2 and 3) are clearly important, but are difficult to analyse in the field.

(*d*) *Effect of conditioning.* Evidence on this point from the field trials is

not very clear, but it seems probable that the decline in the amount of bait taken during prolonged prebaiting is due to the mice reverting to the food on which they have been accustomed to live.

3. THE INCLUSION OF MASKING SUBSTANCES IN BAIT

A number of authorities recommend including certain substances with the bait. For instance the U.S. Bureau of Biological Survey (1937) suggests for house mice a strychnine bait to which is added about 0·2% of sodium bicarbonate, evidently with the intention of masking the bitter taste of the strychnine. We have done only very little work upon this subject, but certain experiments have shown roughly the tolerance ranges of wild mice to such substances without necessarily demonstrating their practical efficiency. In Chapter 9 it is shown that mice have practically no ability to detect a poison bait at their first experience of it, a fact which is confirmed for white mice by Rzóska's experiments (see Ch. 5) on the times of hesitation and refusal

TABLE 33. *Experiments using sodium bicarbonate as a mask*

No.	*Concentration*	*Bait*	*Type of test*	*Procedure*	*Result*
	%				
1	0·166	Rolled oats	Field test in grocer's shop	Choice given of 22 plain bait points and 22 with bicarbonate	All but 1 with bicarbonate eaten (possibly not found)
2	0·5	Rolled oats + 5% As.	Field test in vole cellar	Given after previous arsenic bait	Poison take increased; obvious masking effect of bicarbonate
3	0·3	Rolled oats	,,	Given immediately after plain rolled oats	No drop in take
4	0·5	Rolled oats + 10% BC	,,	Given after previous BC bait	Very high take; obvious masking effect of bicarbonate
5	0·5	Rolled oats	,,	Given immediately after plain rolled oats	Drop in take. ? too strong or mice shy from 4 immediately preceding
6	1	,,	Free-feeding test (2 expts.)	,,	No drop in 2 days in either experiment
7	1	Rolled oats + 15% As.	,,	Given after experiment 6	Good take, but less than control without bicarbonate (6·4% : 23%)
8	1	Rolled oats + 20% As.	,,	,,	Good take, but less than control without bicarbonate (4·2% : 11·4%)

N.B.—Poison take is assessed by the ratio to the last day's prebait take.
As = arsenious oxide; BC = barium carbonate.

of poison baits given by hand. There is, however, some slight evidence that a masking substance may overcome shyness, when mice who have recovered from a sublethal dose of a poison, are offered it a second time. This matter is perhaps worth further investigation, but to us it has always seemed simpler at a second application to change the poison. However, this may not always be possible, so we have summarized our information on masking substances in Table 33.

These results show that mice will readily eat up to 1% of bicarbonate mixed with their food, and that 0·5% has the effect of masking either an arsenic or barium carbonate poison bait. Perhaps 1% is rather too high (see experiments 7 and 8). When it is necessary to repeat the same poison in a second treatment, the addition of 0·2–0·5% of this substance, either in the poison bait or in both the prebait and the poison bait is certainly worth trying.

Further experiments using common salt as a mask are summarized in Table 34.

TABLE 34. *Experiments using sodium chloride as a mask*

No.	*Concentration*	*Bait*	*Type of test*	*Procedure*	*Result*
	%				
1	0·66	Oatmeal	Field test in vole cellar	Given immediately after plain oatmeal	Very slight drop in take
2	0·66	Oatmeal +10% BC	,,	Followed 1 after previous trial with BC in plain bait	Very poor take; did not mask the BC
3	5	Oatmeal	,,	Given immediately after plain oatmeal	Take dropped to 0 over 7 days. Too high
4	2	Rolled oats	Free-feeding test (2 expts.)	Given immediately after plain rolled oats	No drop in take in either experiment
5	2	Rolled oats + 15% As.	Free-feeding test	Followed 4	Good take, but less than control without salt (8%:23%)
6	2	Rolled oats+ 20% As.	,,	,,	Good take, but less than control without salt (3·3%: 11·4%)
7	2	S.r.m.	Field test in flour stack	Given immediately after plain s.r.m.	No drop in take
8	2	S.r.m.+ 2% ZP	,,	Following 7. Previous poisoning with ZP in plain s.r.m.	Poison take higher than first treatment. Obvious masking effect

As = arsenious oxide; BC = barium carbonate; ZP = zinc phosphide.

The results here are rather similar to those with sodium bicarbonate, except that the concentration needs to be higher. In the first two experi-

ments it was clearly too low and in the third too high. Two per cent., on the other hand, is readily taken, and, if we may judge from the last experiment, masks the poison satisfactorily. Even so, its effect, if given in an *initial* poison bait, is to reduce the amount eaten compared with the control without the salt.

The only other substance tested as a mask was castor sugar mixed with the bait at a concentration of 10%. The main experiments upon this have already been mentioned in the section on red squill in Chapter 5, where it was noted that the addition of the sugar made no difference to the amount of squill bait eaten. The actual figures for comparison are given in Table 35.

TABLE 35. *Comparison of poison bait take with and without 10% sugar*

	Poison bait take per cent. prebait take	
	Without sugar	*With sugar*
Females	6·4% (4 observations)	5·5% (3 observations)
Males	11·8% (5 ,,)	12·3% (6 ,,)

We have already described in section 2 of this chapter an experiment in which mice were offered a choice of rolled oats plain and rolled oats with 10% sugar and with 20% olive oil. They preferred the sugar bait for a short while during the middle of the experiment, but grew tired of it. The same thing also occurred in a field test at a food store (pp. 111–12).

Sugar is no help in masking the taste of squill, but on the contrary there is a distinct suggestion that if it is used for too long, mice will tire of it.

REFERENCE

U.S. BUREAU OF BIOLOGICAL SURVEY (1937). 'Directions for destroying house mice.' Leafl. Bur. Biol. Surv. U.S. Dep. Agric. BS-78: 1–2.

APPENDIX

Actual figures of amounts eaten in experiments (in grammes)

1 *a*

Nov.:	*13*	*14*	*15*	*16*	*17*	*18*	*19*
Rolled oats . .	18·00	14·50	17·00	11·50	12·50	10·00	11·75
Wheatmeal . .	15·25	28·75	26·00	25·00	24·75	29·00	26·75
Breadcrumbs .	3·25	2·25	0·00	0·25	0·50	0·00	0·00
Total . .	36·50	45·50	43·00	36·75	37·75	39·00	38·50

1 *b*

Dec.:	*1*	*2*	*3*	*4*	*5*	*6*
Rolled oats . . .	19·25	19·00	21·50	15·50	18·00	22·50
Wheatmeal . . .	17·00	19·25	15·50	18·50	14·75	16·00
Breadcrumbs . . .	2·25	0·25	1·00	0·25	0·00	0·25
Total	38·50	38·50	38·00	34·25	32·75	38·75

1 *c*

	Dec.		*Jan.*			
	30	*31*	*1*	*2*	*3*	*4*
Rolled oats . . .	22·75	18·25	16·50	14·50	17·25	17·25
Wheatmeal . . .	16·75	13·25	13·00	12·00	11·75	8·75
Breadcrumbs . . .	19·25	16·25	17·25	21·50	18·00	19·00
Total	58·75	47·75	46·75	48·00	47·00	45·00

2 (i)

	Jan.			*Feb.*				
	29	*30*	*31*	*1*	*2*	*3*	*4*	*5*
R.O.plain	21·75	21·00	4·50	4·50	8·75	22·00	29·00	30·00
R.O.+ 10% sugar .	7·25	10·25	28·25	28·25	20·50	7·50	8·25	14·75
R.O.+ 5% oil .	1·50	11·00	16·75	16·75	15·50	26·75	27·50	20·00
Total .	30·50	42·25	49·50	49·50	44·75	56·25	64·75	64·75

Feb.:	*6*	*7*	*8*	*9*	*10*	*11*	*12*
R.O. plain . .	21·75	15·50	8·00	19·00	18·00	4·50	3·00
R.O.+10% sugar .	9·50	10·00	8·50	9·50	6·50	4·25	6·50
R.O.+5% oil .	34·75	53·25	40·50	34·00	32·50	32·50	38·25
Total . .	66·00	78·75	57·00	62·50	57·00	41·25	47·75

APPENDIX (*cont.*)

2 (ii)

	Jan.			*Feb.*				
	29	*30*	*31*	*1*	*2*	*3*	*4*	*5*
R.O.plain	35·25	22·50	21·75	22·75	19·75	16·50	8·50	5·25
R.O.+ 10% sugar .	18·75	22·50	28·50	24·75	14·50	6·25	3·25	2·00
R.O.+ 5% oil .	15·50	23·00	25·25	20·00	22·75	37·00	39·00	52·50
Total .	69·50	68·00	75·50	67·50	57·00	59·75	50·75	59·75

Feb.:	*6*	*7*	*8*	*9*	*10*	*11*	*12*
R.O. plain . .	5·50	3·25	6·25	6·50	4·00	2·25	1·50
R.O.+10% sugar .	3·00	2·00	5·00	2·00	2·25	0·25	0·50
R.O.+5% oil .	45·50	44·75	17·50	32·50	38·50	47·50	50·50
Total . .	54·00	50·00	28·75	41·00	44·75	50·00	52·50

3 (i)

March:	*16*	*17*	*18*	*19*	*20*	*21*
Rolled oats:						
+5% oil . . .	7·00	3·25	3·00	0·00	0·00	0·25
+10% oil . . .	2·50	3·50	1·75	2·50	2·00	0·25
+20% oil . . .	10·50	16·00	20·00	20·50	18·75	21·25
Total . . .	20·00	22·75	24·75	23·00	20·75	21·75

3 (ii)

March:	*16*	*17*	*18*	*19*	*20*	*21*
Rolled oats:						
+5% oil . . .	4·25	2·25	0·75	1·75	4·50	4·25
+10% oil . . .	4·00	4·50	3·50	3·25	1·75	1·75
+20% oil . . .	4·75	13·75	16·00	15·75	16·00	16·75
Total	13·00	20·50	20·25	20·75	22·25	22·75

4 (i)

	April				*May*	
	27	*28*	*29*	*30*	*1*	*2*
Rolled oats:						
+20% olive oil . .	24·00	20·25	22·00	18·25	19·00	17·00
+20% linseed oil . .	1·00	0·00	0·00	0·00	0·00	0·00
+20% ground nut oil .	2·75	3·50	7·00	7·75	8·00	15·50
Total	27·75	23·75	29·00	26·00	27·00	32·50

APPENDIX (*cont.*)

4 (i) (*cont.*)

May:	*4*	*5*	*6*	*7*	*8*
Rolled oats:					
+20% olive oil	10·75	15·25	12·00	10·00	14·25
+20% linseed oil. . . .	0·00	0·00	0·00	0·00	0·00
+20% ground nut oil . . .	3·00	15·00	17·50	19·00	22·50
Total	13·75	30·25	29·50	29·00	36·75

4 (ii)

	April				*May*	
	27	*28*	*29*	*30*	*1*	*2*
Rolled oats:						
+20% olive oil . .	19·50	15·25	11·75	9·75	10·00	13·00
+20% linseed oil . .	1·00	0·00	0·00	0·00	0·00	0·00
+20% ground nut oil .	3·50	3·50	7·00	11·25	10·75	15·50
Total	24·00	18·75	18·75	21·00	20·75	28·50

May:	*4*	*5*	*6*	*7*	*8*
Rolled oats:					
+20% olive oil	7·75	8·00	6·75	7·50	11·50
+20% linseed oil. . . .	0·00	0·00	0·00	0·00	0·00
+20% ground nut oil . . .	5·25	11·50	11·00	13·25	16·00
Total	13·00	19·50	17·75	20·75	27·50

5

Aug.:	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
Sausage-rusk mash (dry wt.)	5·00	12·50	11·50	12·00	13·50	18·00	15·00	18·50
Rolled oats .	37·00	34·00	34·00	34·00	40·00	30·00	30·50	26·00
Total .	42·00	46·50	45·50	46·00	53·50	48·00	45·50	44·50

Aug.:	*20*	*21*	*22*	*23*	*24*	*25*	*26*
Sausage-rusk mash (dry wt.) . .	22·50	26·00	33·50	26·00	30·00	24·50	28·00
Rolled oats . .	22·00	16·50	18·50	28·50	10·50	12·50	12·00
Total . .	44·50	42·50	52·00	54·50	40·50	37·00	40·00

APPENDIX (*cont.*)

5 (*cont.*)

	Aug.					*Sept.*	
	*27**	*28*	*29*	*30*	*31*	*1*	*2*
Sausage-rusk mash (dry wt.) . .	26·00	25·00	22·50	25·00	22·50	20·00	26·50
Rolled oats . .	16·00	21·50	21·00	23·00	20·50	13·00	16·50
Total . .	42·00	46·50	43·50	48·00	43·00	33·00	43·00

* Water given from this date.

8

THE USE OF PLAIN BAIT BEFORE POISONING IN CONTROLLING HOUSE MICE

1. THE EFFICIENCY OF PREBAITING IN ATTRACTING MICE

AUTHORITIES often state that house mice can be successfully poisoned without any preliminary baiting with plain food. This is the first practical problem we must answer in the light of the information we have now gained on movements and range, feeding habits, and food preferences of mice.

There are two advantages in what has come to be known as 'prebaiting' which make it a necessity in combating brown rats. In the first place it is possible by laying down a surplus quantity of some attractive plain bait to draw the rats in somewhat less than a week from their original food supply to the extent that they will come each evening at the start of their feeding period and feed mainly upon the bait provided for them. Rzóska examined the stomach contents of a large series of poisoned rats (see Vol. 2, Ch. 9) and showed that prebaited rats have usually eaten little but the bait put down for them, and therefore prebaiting exposes them to a much greater hazard of being poisoned than if they were wandering from one source of food to another. In the second place, since rats can be drawn in this way from their 'natural' food, it is possible by measuring the consumption of plain bait to arrive at a reasonable estimate of the numbers of any field population. This often makes it possible to measure with some accuracy the success of a poisoning campaign in terms of the actual number as well as the relative number of the population killed.

With house mice we have seen already from Chapter 2 that baits must be liberally scattered over the area infested because the range of a single mouse is small, and unless every range contains at least one bait, there is no guarantee that the mice will even be exposed to the risk of being poisoned. On the other hand, if we try to visualize the protective behaviour of a mouse within this small range, we must conclude that its high development of kinaesthetic sense means that it will be in constant contact with the minuter details of its range, and by continually moving about it and familiarizing itself with any changes, it will be unlikely to overlook a bait point placed within its reach. Thus, if the bait is attractive enough (this point was dealt with in the last chapter), it will probably eat some of it straight away. An important thing about the behaviour of mice is that the appearance of new objects among their surroundings does not cause the intense shyness exhibited by rats; on the contrary something new needs investigating at once so that

it may be approached on familiar terms. So far, therefore, there is no particular evidence that prebaiting is valuable against house mice.

The next matter we must consider is how much of a new bait mice will eat and how consistently they will continue eating it. The experiments described in Chapter 6 have shown that the mouse's feeding is characterized by perpetual restlessness and a continual movement from cover box to feeding area and from one bait point to another. The number of visits paid to a food tray during a single night may run to several hundreds so that only a very small amount of food is taken at any one visit.

Thus one of the main difficulties in attracting mice to plain bait is to overcome somehow this tendency to move from point to point, a difficulty which is greatly exaggerated if the habitat contains abundance of food already on which the mice are accustomed to feed. Further, the degree of individual variation in behaviour makes the matter even worse, since some may be faithful to their original food entirely or may abandon the new food after only a short trial.

2. STOMACH CONTENTS OF POISONED MICE

Evidence about how successful prebaiting is with mice has been obtained from Rzóska's examinations of the stomach contents of poisoned mice.

The biggest series he examined came from a poisoning test in the basement of the Department of Pharmacology in Oxford. Here prebaiting with rolled oats was carried on for more than a week with considerable success. Baiting was first carried out for a week at two places and a level of about 80 g. of bait a day was being taken by the end of this time. The mice were fairly hungry because their main supply of food which was rat cubes (for the laboratory stock of rats) had been locked up and they had to hunt for spilled fragments and the crumbs around the animal cages. At the end of this week we put down another nine points of bait and the daily consumption went up to a peak of 128 g. We believed that the mice had been prebaited as efficiently as possible in a place where the normal food supply could not be entirely removed. After poisoning with zinc phosphide we picked up nineteen corpses and the detailed results are given in Table 36.

These results suggest strongly that prebaiting has limitations for house mice. Conditions were as favourable as possible for drawing the mice to bait, and all appearances suggested that this had been achieved, but only about a third of the mice had made their main meal from the poison bait. This may be seen more easily from the analysis of the results in Table 37.

It is even more surprising that another third of the mice fed mainly on rat cubes, so that the effect of prebaiting was to influence only two-thirds of the mice more favourably to being poisoned. The remaining third behaved much in the same way as if direct poisoning had been carried out.

TABLE 36. *Stomach contents of poisoned mice from Department of Pharmacology, Oxford*

Females	*Wt. (g.)*	*Total content*	*Poison bait*	*Remarks*
1	21·5	1·3 g.	0·9 g.	Only poison bait distinguishable
2	14·8 (pregnant)	0·9	tr.	Small amount rat cubes, poison not distinguishable
3	27·4 (pregnant)	1·7	1·2	Only poison bait distinguishable
4	13·4	1·2	0·8	" " "
5	12·3	1·2	0·5	Poison bait mixed with rat cubes
6	9·5	1·0	tr.	Moderate amount food, poison bait not distinguishable
7	11·4	0·7	0·1–0·2	Poison bait mixed with rat cubes
8	6·3	0·3	0·2	Only poison bait distinguishable
9	4·8	0·2	tr.	Small amount of rat cubes
10	6·7	0·4	0·1	Poison bait mixed with rat cubes
11	11·5	2·1	tr.	Only rat cubes distinguishable

Males	*Wt. (g.)*	*Total content*	*Poison bait*	*Remarks*
1	15·4	1·9	tr.	Only rat cubes distinguishable
2	12·2	0·7	0·1–0·2	Poison bait mixed with rat cubes
3	12·8	0·5	0·3	Only poison bait distinguishable
4	14·5	1·0	0·3	Poison bait mixed with rat cubes
5	16·0	1·0	0·6	" " "
6	6·0	0·3	< 0·1	Small amount of poison bait on top of rat cubes
7	*c.* 5·0	0·5	0·3	Only poison bait distinguishable
8	15·5	2·1	tr.	As No. 6

TABLE 37. *Summary of stomach analysis results from mice poisoned at Department of Pharmacology, Oxford*

	Number of mice with			
	Poison bait only	*Poison bait mixed with food*	*Mostly food*	*Total*
Males . . .	2	3	3	8
Females . .	4	4	3	11
Total . . .	6	7	6	19

3. STOMACH CONTENTS OF TRAPPED MICE

Lest anyone should suspect that the changing from plain bait to poison bait affected the feeding behaviour of the mice by making them shy and driving them back to their 'natural' food, we quote the following results of experiments, in which prebaiting was carried out for some while and then samples of the mice were trapped.

A flour stack in a M.O.F. buffer depot was baited by Rzóska with moist sausage-rusk and a high level of consumption reached (80–90 baits per day). Traps were then placed at a certain number of the bait points and were left for some days unset, but baited with the plain rusk. They were then set for one night and the eight mice caught were examined to discover to what extent they had been feeding on the bait. Of these eight mice all had flour in the stomachs; two were quite full, five had a moderate amount and only one had a small amount. Thus in spite of several weeks of seemingly successful prebaiting the mice were still feeding largely on the flour and only coming to the bait secondarily.

Again in a large draper's store at Oxford, where food was scarce, mice were prebaited with small piles of dry rolled oats, which they took very well. Trapping produced fifteen corpses and examination of these showed that four had the stomachs quite full of food, five fairly full, four half-full, and only two entirely empty. Thus the great majority of these mice would have been poor subjects for poisoning. This does not mean to say that mice cannot be poisoned successfully even though they only come to the poison bait secondarily. They can, as the experiment in the Department of Pharmacology above shows, but there must always be a greater chance of their escaping with a sublethal dose than in the case of rats, which will come out and feed straight away on poison bait. This makes it all the more important that the correct choice of baits for mice should be made and that they should be properly sited to catch the attention of as many as possible of the population.

4. THE USE OF PREBAITING TO SHOW THE DISTRIBUTION OF MICE

Thus quite apart from the question of whether prebaiting is valuable for drawing mice away from their 'natural' food supplies, even in a small degree, we arrive at the conception of using this system, which was developed for rats, with quite a different intention. The wide distribution of small piles of plain bait is one of the simplest ways of analysing the habitat of mice in terms of the relation of food to cover, the importance of which we insisted upon in Chapter 2. The instances quoted there showed that sometimes very unexpected information turns up from this method of tackling an infestation, and, if this reveals that the movements of the mice within the area concerned are canalized in certain parts of it, this is of vital importance in siting baits so as to intercept mice on their journeys from cover to food. A complete knowledge of tracks and runways is far more important in dealing with mice than the conditioning effect implied by the term prebaiting. We have to be content with falling far short of complete success in bringing the mice to the bait if we can counterbalance this by adroitness in bringing the bait to the mice.

If this is so, does the case for prebaiting as such break down? We can

always trace runways by plaster of Paris patches or by searching for smears, droppings, and so on, and save valuable bait. But this is unsatisfactory for two reasons: in the first place tracing by means of bait piles is very much easier and surer than any other method and gives a picture which is much better defined quantitatively. We shall deal more fully with this question in Chapters 10 and 11. In the second place it is not accurate to say that prebaiting has no effect at all in conditioning mice to feed on the bait provided. The effect may vary widely in different habitats and with different populations of mice; sometimes direct poisoning can be very successful, but on balance there are more cases where some benefit, however small, is derived from prebaiting. In dealing with house mice, whose movements and feeding habits render poisoning so difficult, any small advantage of this kind should be used.

5. THE SUBSIDIARY USE OF PREBAIT TO ATTRACT MICE

We may further consider this question of prebaiting for its own sake under two heads: (1) Does it ever succeed in drawing in mice to which poison bait would be otherwise unavailable? (2) Does it ever, if continued, lead mice to come to the bait more and more frequently? If either of these effects can be demonstrated in some degree, prebaiting will be worth while.

(1) The experiments on house mouse ranges given in Chapter 2 show that there will be little chance of using prebaiting to draw in mice except in certain circumstances. Such circumstances may, however, be sufficiently prevalent, when we consider the country as a whole, for us to watch out for them. In the range experiments we noted how quick was the adjustment of the mice when all bait points were removed and a single one only placed at one end of the cellar. Where food is scarce, therefore, mice can readily be persuaded either to move into new ranges or to shift the focus of their already existing range. In the field experiment quoted on p. 23, where mice were visiting the cellar of a dry cleaner's shop and nibbling the labels on the parcels, there was no doubt that more mice were drawn in when prebait was offered simply because food was scarce. In this instance direct poisoning would have had practically no effect on the population, since for the first few days very little bait was eaten.

(2) There is little doubt that prebaiting does sometimes and to varying degrees increase the attention that mice will give to plain bait, and thus, presumably, to the subsequent poison bait. The result of examining the corpses from the Department of Pharmacology proves that some mice took practically nothing but poison bait. Mice may, then, be persuaded by prebaiting to place the bait rather higher on their list of 'priorities' than they otherwise would; the bait may still be secondary to their normal food supply, but they may attend to it earlier during the feeding period, and thus come to it hungrier than they would without some habituation.

6. GAP BAITING

All this speaks for prebaiting, though we must always remember that its effect can only be a restricted one. Prebaiting only forms part of the methods to be used against mice and can never become the sole key to the situation as it has very nearly done with rats. This point is well illustrated by two rather long and painstaking experiments carried out in an Oxford food store to discover whether by leaving gaps in the days of baiting the rate of consumption could be stimulated. With rats it frequently happens that, once they have 'taken' to a bait, if we omit to provide it for a day they will be all the more eager for it on the next day. Such a stimulus produced no results with house mice. During the 'gap' day or days they must, one supposes, merely have fallen back on their staple food, thus showing that the bait provided, although taken well, could only have been a snack for them outside the main courses.

We selected two flour stacks and baited them with moist sausage-rusk daily until a reasonably stable level of consumption had been reached. One-day and 2-day gaps were tried both during the prebaiting and before poisoning, and each time baiting was missed in one stack only, so that the other should remain as a control. The figures in Table 38 show the course of the experiment.

TABLE 38. *The effect of leaving gaps during the course of baiting*

Day:	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*19*	*20*	*21*
Stack 1 .	20	30	..	25	26	28	36	38	33	33	..	..	..	26	29
Stack 2 .	36	39	39	38	39	41	..	..	45	47	46	37	..	38	45

Day:	*22*	*23*	*25*	*26*	*27*	*28*	*29*	*30*	*32*	*33*	*34*	*35*	*36*	*38*
Stack 1 . .	19	23	22	..	..	..	0	1	21	24	33	37	34	43
Stack 2 . .	41	41	26	32	46	..	0	8	18	16	14	30	40	38

Day:	*39*	*40*	*41*	*42*	*43*	*45*	*46*	*47*	*48*	*49*	*50*	*52*	*53*	*54*
Stack 1 . .	30	37	44	32	43	45	40	..	..	..	14	37	37	41
Stack 2 . .	31	..	..	21	30	43	31	42	34	..	31	43	36	37

The figures represent the number of moist sausage-rusk baits (each about 3 g. in weight) wholly or partly eaten during each 24 hours. On the only single-day gap that was tried the result was to decrease rather than to increase the amount taken. Subsequently only 2-day gaps were tried. Two of these (days 12/13 and 40/41) occurred during the course of prebaiting; one of them again showed a decline, the other an increase which was, however, maintained during the next 2 days, and so would probably have occurred even without the gaps. The other three trials occurred before poisoning, so

that the results are a little more difficult to judge. There is a slight tendency for the postbait in the gap-baited stack to be slightly lower than in the other, which might mean that the mice were encouraged to take more poison, but in every case the postbait recovered to its normal level, so that the result is of no significance.

On day 42 we tried to check whether leaving a gap in baiting quickened the rate at which the bait was eaten, even if it did not increase the quantity taken during the whole night. Accordingly we baited both stacks at 6.30 p.m. and checked the baits at half-hourly intervals for the following 2 hours. If anything, the baits were taken quicker in the control stack and at the end of the 2 hours the same number had disappeared from both stacks. The figures are given in Table 39.

TABLE 39. *Rate of disappearance of baits in two flour stacks*

	½ *hr.*	1 *hr.*	1½ *hrs.*	2 *hrs.*
Stack 1 with no gaps in prebaiting .	4	2	0	0
Stack 2 with baiting omitted on previous 2 days	2	1	0	3

These results will serve to remind us that prebaiting does not change the feeding habits of mice in any permanent or decisive way. They may come somewhat more readily to the bait, especially where food is scarce, but except in such circumstances it is difficult to make them take to the bait as their main food.

7. WHEN AND HOW TO USE PREBAITING FOR MICE

These considerations suggest that at times prebaiting may not be absolutely necessary for poisoning house mice, but the difficulty is to know on what occasions we can dispense with it. The only way to decide this is to carry out the full campaign, which is rather putting the cart before the horse. In general we may allow that prebaiting is unnecessary either where the mice are very hungry through scarcity of food, or where the bait is clearly more palatable than the staple food (e.g. in corn-ricks where water is scarce). Even so, it is necessary to disperse the bait in small quantities over a wide area (cf. the number of bait points used for corn-stacks, Ch. 13) so as to reach every mouse.

In other environments the following illustrations show the wide range of variation in the speed with which mice approach prebait, in some places beginning at the highest level straight away, in others taking some time to work up to it.

Thus it is almost impossible to predict the localities in which bait will be taken in quantity straight away. The oat and flour stacks in Table 40 were to all appearances similar and the physical environment the same, yet there

was considerable variation in the amount of delay before the peak was reached.

TABLE 40. *Time taken to build up to a plateau in prebait take*

Type of locality	*Bait used*	*No. baits laid*	*Take (1st day)*	*Average plateau*	*Lag*
Grocer's store . .	½ g. rolled oats piles	100	97	Baiting not continued	Nil
M.O.F. buffer depot					
Oat stack *a* . .	3 g. baits of s.r.m.	26	24	Bait changed	,,
,, *b* . .	,,	50	46	46	,,
,, *c* . .	,,	100	25	45	2 days
Flour stack *a* . .	,,	100	14	36	4 ,,
,, *b* . .	,,	100	23	45	4 ,,
Oat stack *d* . .	,,	75	39	57	7 ,,
,, *e* . .	,,	75	40	45	8 ,,

Finally, an example will make clear the way in which the Bureau's method of prebaiting for mice combines searching and trace-testing with the attracting of the population's interest inherent in the technique used for rats.

On the first day a search of the infested premises is made and small bait points of about ½–1 g. of rolled oats are placed liberally wherever there are signs of mice or likely runways, and slightly less liberally where there are no signs of mice. The next day usually reveals certain focal points where the bait piles have been cleaned up, and the procedure is then to increase the number of piles in these areas, possibly at the same time reducing those in the unpatronized places. In this way the mice are narrowed down in their ranges wherever interception has been successful and the amounts of prebait can be increased to saturation, which is the time to lay the poison bait. Table 41 gives the figures for a treatment in a confectioner's shop, showing the continual increase of the amount of prebait put down. What the table does not reveal is how the baited areas are gradually narrowed down until the main centres of the infestation are clearly defined. To do this successfully is partly a matter of judgement and partly of practice: at first the process takes some time, perhaps a week, but with improving skill there is no reason why it should not be done satisfactorily in 2 or 3 days.

TABLE 41. *Course of prebaiting in a confectioner's shop*

Day:	*1*	*2*	*3*	*4*	*5*	*6*
½ g. bait piles:						
No. put down	36	43	54	83	102	105
No. taken	19	27	31	58	56	70

In this instance on the final day of the prebaiting all the seventy baits taken were at two focal points, whereas at the beginning the whole premises seemed to be overrun with mice.

The only disadvantage of prolonging the prebaiting (apart from it being uneconomic in practice) is that the mice may lose interest in the bait. The reality of this phenomenon has been discussed in the previous chapter and further field evidence is given in Chapters 10 and 11. Even so, it is worth doing several extended prebaitings, if merely for the sake of sharpening one's judgement.

9

THE BEHAVIOUR OF THE HOUSE MOUSE TO POISON BAIT

1. INTRODUCTION

THE material presented in this chapter is so complicated that we must give some preliminary guide to its arrangement and to the sequences of thought which underlie it.

The last three chapters have analysed the behaviour of the house mouse to plain bait and have shown that in the competition between 'natural' food and the bait which is placed for control purposes the latter is only favoured under exceptional circumstances. Certain principles for circumventing these difficulties have been discussed and shown to be valuable in the practice of control. We can easily understand, therefore, that when the above-mentioned competition is replaced by one between 'natural' food and poison bait there will even be less reason for the latter to be favoured.

The first phase in analysing the behaviour of house mice to poison bait is to find out how mice approach such a bait when they have never experienced one before. The failure of the early field control tests carried out on mice by the Bureau suggested that they might be able to avoid a poison bait by straightforward detection and without any help or association from a previous experience. Accordingly most of this chapter deals with their behaviour to an initial poison bait and discusses whether their behaviour enables them to detect the poisonous nature of the food before a lethal dose has been eaten. A special series of experiments bearing upon this basic question were designed and carried out by means of the recording machine described in Chapter 6.

Subsequent sections all deal with the effects on the behaviour of mice of an initial experience with a poison bait: first, whether such experience influences their subsequent approach to plain bait; secondly, whether the attitude to a second offering of poison bait is modified by the experience of the first; and, lastly, what will be the effect of the various combinations of an old poison in a new food, a new poison in an old food, and a new poison in a new food. In each section experimental results are cited from the field and the laboratory together with a special set of tests done (as mentioned above) with the recording machine.

2. PROCEDURE

The experiments in Table 46 were mostly carried out by a standard procedure. Only one experiment was done upon tame mice; the rest were wild.

Each mouse was housed in a separate cage of a standard type made of glass and circular (dimensions $8\frac{9}{10}$ in. diameter and 5 in. high) with a lid of perforated zinc. Each cage was provided with a cover box ($6 \times 2 \times 1\frac{1}{2}$ in.), which helped in changing and weighing the food since, when alarmed, the mouse always took refuge there. Water bottles of the drip-feed type were provided for each cage.

The mice, after being weighed and sexed, were put in these cages and allowed to settle down for 3–4 days. The experiment was not usually begun until all were eating a normal daily amount of dry food or its equivalent (3·4 g.). Food was given in small circular tin trays, which minimized the amount spilled, and the daily consumption was weighed on a balance which was accurate to the nearest 0·1 g. Where wet food was supplied, e.g. moist sausage-rusk, generally the residue was dried each morning and the take calculated in terms of dry rusk. Poison bait was given in exactly the same way, but often the amount taken was so small that it was within the limits of error of the balance used.

The food store experiments, results of which are summarized in Table 48, were carried out in a M.O.F. buffer depot in the outskirts of Oxford. This was almost entirely filled with stacks of sacked flour and oats, and the floor space occupied by each stack varied from 16×18 ft. to 35×36 ft. The space between the stacks varied, but usually consisted of a narrow gangway 2–3 ft. broad. Lines of plaster of Paris showed that the mice travelled only rarely between different stacks. In the flour stacks the sacks were piled up almost to the roof (*c.* 15 ft.) but the oat stacks were lower (*c.* 8 ft.), consisting generally of two layers of sacks placed on their ends and a top layer placed on their sides. Baiting was done throughout with moist sausage-rusk. To distribute the baits easily and quickly small tubes with spring plungers inside them were designed, so that the tube could be pressed into the bait and a small cylinder of fairly standard size and weight (*c.* 3–4 g.) pressed out rather like toothpaste. This was most useful for baiting higher up in the stacks because the baits clung to the apex of the V-shaped crevice made when one sack is laid on top of another.

Baits were generally changed daily, and takes were recorded in three categories; complete, partial, and no take. Thus a fairly accurate quantitative picture was obtained (most stacks had at least fifty baits in them) without what would have been a very tiresome process of weighing. Takes recorded as complete may occasionally have been only partial, since it was difficult to make sure whether baits had been removed out of sight. In one stack which we searched, when it was eventually broken down, we found very few complete baits, although the stack had been baited daily for some 6 weeks. In addition we found we could modify the consistency of the bait by the amount of pressure we applied when loading the baiting tube. If the bait was not pressed in too tightly, a cylinder of rather a crumbly nature was produced, and no mouse could have removed one of these whole. We

realized this about a fortnight after the experiments were started, and took care that thenceforward all the baits should be of this crumbly nature. Furthermore, baiting sites were usually established a foot or two inside the stack, so that mice did not have to come out of cover to feed. This would help to stop any temptation to carry off the bait. All bait sites were marked with chalk so that none should be overlooked.

During some of the experiments we had to find some way to determine whether bait points had been visited at all apart from whether bait had been taken. To do this we placed the bait on a smoothed patch of plaster of Paris about 4 in. in diameter. Visits were recorded simply by presence or absence of footprints, and the surface of the plaster smoothed down each day. Only about half of the baiting sites in a stack were so treated, since we thought this would be a sufficient sample.

Temperature in the food store was cool and light generally dim because the windows were blacked out with paint. These were only opened when work was going on in the vicinity. Trapping only had been done to mitigate the mouse trouble before our experiments started.

Lastly there is the special series of experiments done with the recording machine. We have already described this technique in Chapter 6, and the only modifications necessary were those involved by the provision of the poison bait. Usually, when such baits were given, they were put into the cages just before the evening period of activity was due to start (i.e. about 5 p.m.). This meant that the last prebait had been weighed and all food removed from the cage 7 hours before, so a very slight (because of the small amount of day-time feeding) fasting was imposed before the poison was given.

In every case the poison used was zinc phosphide, since previous experience had shown that this was the most promising for dealing with mice.

We found it was most important to wipe out the cages carefully after each poison experiment with a wet cloth, otherwise enough traces of poison might be left on the floor for other mice to pick it up and die.

3. INITIAL POISONING AND ITS EFFECTS

The results with the recording machine will be considered first. Nine experiments, involving twenty-five mice, were more elaborate versions of the cruder free-feeding tests. For each one three mice were installed in their separate compartments and left with a supply of rolled oats and water until they had settled down. Then the recording machine was started and charts for 2 or more days were obtained; finally, poison bait replaced the plain bait in three different concentrations (2, 5, and 10%), so that the way in which mice approached baits could be analysed from the charts.

The most striking result of these experiments was how greatly the mice varied in the time taken before they would eat the poison bait. This occurred despite their being accustomed to take their food always from the feeding

trays, and despite their being presented with poison bait in these trays with no alternative food.

The length of time between the placing of the poison and the last record on the chart is taken as the time of survival, that is the time during which they survived the risk of being poisoned before finally succumbing to symptoms sufficiently severe to prevent their visiting the trays. The spread of the recorded times is shown in the frequency distribution in Table 43. It should be noted that all but a single mouse in these experiments finally took a lethal dose of poison, while the one survivor died on the day after the experiment ended, presumably from having picked up a crumb of poison that was overlooked in cleaning the cage.

TABLE 42. *Experiments on poison bait take with activity recording machine*

Mice used	*Type of expt.*	*Pre-bait*	*Poison bait*	*Result*	*Take poison bait/last day's prebait*	*Survival time*
			%			
♀ 11·5 g.	Approach to initial poison bait; no alternative food	o	o/z 10	Survived	o/3 g.	> 24 hrs.
♀ 27 g.	,,	o	o/z 2	Died	0·9/4·7	9 hrs.
♀ 22 g.	,,		5	,,	0·5/4·2	No record
♀ 22 g.	,,		10	,,	0·5/4·0	< 5 hrs.
♂ 19 g.	,,	o	o/z 2	,,	0·5/4·5	< 6 hrs.
♀ 14·5 g.	,,		5	,,	0·25/3·9	< 3½ hrs.
♀ 23 g.	,,		10	,,	0·15/4·8	13 hrs.
♀ 21 g.	,,	o	o/z 2	,,	0·7/4·4	< 5 hrs.
♂ 15·5 g.	,,		5	,,	0·7/4·2	8 hrs.
♂ 16 g.	,,		10	,,	0·3/4·2	< 2 hrs.
♀ 13 g.	,,	o	o/z 2	,,	No record	No record
♀ 18 g.	,,		5	,,	0·5/4·75	< 2 hrs.
♀ 11·5 g.	,,		10	,,	No record	No record
♂ 17·5 g.	,,	o	o/z 2	,,	0·6/2·3	< 7 hrs.
♂ 14·5 g.	,,		5	,,	0·25/3·3	3 hrs.
♂ 18 g.	,,		10	,,	0·3/2·1	5½ hrs.
♂ 18·6 g.	,,	o	o/z 5	,,	0·2/3·2	3 hrs.
♀ 18·1 g.	,,		5	,,	< 0·1/3·2	½ hr.
♀ 15 g.	,,		5	,,	0·1/2·4	No record
♀ 16·5 (pregnant)	,,	o	o/z 2	,,	0·6/5·2	½ hr.
♀ 10·5	,,		5	,,	0·2/2·4	< 2½ hrs.
♀ 16 g.	,,		10	,,	0·1/2·6	½ hr.
♀ 19 g.	,,	wh	o/z 5	,,	0·4/3·3	1 hr.
♂ 19 g.	but poison given		5	,,	0·25/3·4	< 2½ hrs.
♂ 25 g.	in new base		5	,,	0·2/5·4	2 hrs.

o = dry rolled oats; z = zinc phosphide; wh = whole wheat.

From this we see that only 45% of the mice succumbed within 2 hours after the placing of the bait; the rest survived for varying periods, the maxi-

mum of which was 13 hours. It is clear, therefore, that many of these mice would not eat the poison without considerable hesitation, even though under these conditions any prebaiting effect would be at its greatest.

TABLE 43. *Distribution of times of survival from placing of the poison bait at 5 p.m.*

Hours:	0–	0·5–	1·0–	1·5–	2·0–	2·5–	3·0–	3·5–	4·0–	4·5–	5·0–	5·5–	6·0–	6·5–	7+
No. of mice surviving till	0	3	1	2	3	0	3	0	0	2	0	2	0	1	3

However, the mice certainly investigated the bait at once. Every chart showed that visits commenced at the normal time, usually within half an hour of giving the poison, and continued with a normal frequency until a lethal dose was at last eaten.

Since from experiment 1 in Table 46 we see that 1 mg. of zinc phosphide was sufficient to kill one out of four white mice and to cause illness in the other three for 3 days, the average lethal dose for mice cannot be very much above this (standardized toxicity tests were not done upon mice, but one calculated on the rat level would give a figure of from 1·2–1·6 mg. for a mouse of 20 g., which is not badly out of agreement). It is surprising, therefore, to find a mouse eating as much as 18 mg. of zinc phosphide and surviving for 9 hours. The only explanation seems to be that the visits during the first 8 hours must all have been exploratory only and no bait except possibly the most minute scraps was taken. Since warning symptoms develop in mice within 20–60 minutes of the first mouthful of the poison (see Ch. 5), such a mouse must have abstained from proper eating for at least 8 hours.

However, we must remember that control deals with populations and not with individuals. Some 45% of these mice took enough poison to kill them within 1–1½ hrs. of its being offered, and there will probably be in any wild population a proportion that is not unduly suspicious.

These experiments gave further data on the way in which different concentrations of zinc phosphide in the bait are approached, and the results are rather curious (see Tables 44 and 45).

TABLE 44. *Consumption of poison bait (per cent. of last day's prebait take) according to concentration of poison used*

	2%	5%	10%
No. of observations	5	12	5
Consumption (mean)	15·6	8·4	7·6

TABLE 45. *Time of survival according to concentration of poison used*

	2%	5%	10 %
No. of observations	5	10	5
Mean survival time (hours) . . .	5·4	2·7	5·1

The amount of poison bait eaten, when the concentration of poison is only 2%, is about twice the amount eaten at 5%. This suggests a quantitative relation between the amount of bait eaten and the percentage of poison such that a halving of the latter means a doubling of the former. So we might surmise that a standard amount of poison consumed and not the time since the first mouthful controls the onset of warning symptoms. No doubt there is such a relation, but it is surprising to find it when dealing with amounts so much above the supposed average lethal dose for mice. One may note that this relationship breaks down, when we come to the 10% concentration figure, and between 5 and 10% there is little difference in the total amount of bait eaten.

A further surprising thing is that with 2% poison bait the mice survived on the average twice as long as with 5% poison bait. Again this suggests a sliding scale for the onset of warning symptoms, which is very difficult to harmonize with the inference made previously that a long survival time means no real eating except during the last hour or so.

The most likely explanation is that both processes are at work. In the first place suspicion of the bait and delay in eating freely must occur in the mice that survived more than 2 hours: on the other hand, the amounts of poison involved (generally from 10–15 mg., which is a good deal less than the quantities taken during the hesitation and refusal tests by Rzóska, see Ch. 5) are possibly low enough to show a relation between the concentration, the amount of bait eaten, and the time before warning symptoms appear.

On this evidence there is clearly no advantage in field poisoning tests from using a 10% concentration. The results with 5% are even better. In the first place the single survivor was one that was offered the highest concentration, and in the second place the survival times among those that died, although not differing significantly in their mean from the 2% times, differ greatly in their spread (actual survival times for individual mice offered 10% are $4\frac{3}{4}$, 13, $1\frac{3}{4}$, $5\frac{1}{2}$, and $\frac{1}{2}$ hr.). Evidently the behaviour of mice to bait of this strength is much more erratic than it is to lower concentrations. Some mice take enough to die very quickly, but others are much more suspicious and may delay eating for several hours.

These conclusions are confirmed by laboratory experiments done by Rzóska, using the technique described at the beginning of the chapter. All these laboratory experiments apart from the ones in which the recording machine was used, are summarized in Table 46.

Experiments 3–6 in Table 46 were designed to show whether prebaiting had any marked effect, but they also illustrate the fact that most poison baits, if offered without alternative food, will ultimately (i.e. during the course of one night) be eaten. In these cases similar batches of wild mice were given plain food for 2 days, one batch the same as that in which they were to be poisoned (moist sausage-rusk), and the others whole wheat. In

both sets of experiments the only survivors (3 out of 13) were mice which had not been prebaited. Furthermore, in experiments 3 and 4 the mice were watched as they approached the poison bait and the unprebaited ones were more shy of feeding than the others. These differences may or may not be significant, and the advantage of prebaiting for changing the feeding behaviour of mice is probably appreciable though not great. However, in most of the experiments summarized in Table 46 (expts. nos. 1*a*, 3, 5, and 7*a*)

TABLE 46. *Summary of laboratory experiments*

Experiment No.	*Number and kind of mice used*	*Preliminary feeding*	*Poison used*	*Acceptance of poison bait and its effect*	*Duration of illness/ days post-bait*	*Post-bait*	*Acceptance of postbait*
1	4 tame	s.r. 2 days	(*a*) s.r./z 1 mg. in 1-g. pill	All eaten; 1 died	3/8	o s.r.	Preferred at first Preferred later
			(*b*) 1% s.r./z o plain	Nil	o/4	o s.r.	1 preferred Rest preferred
			(*c*) 5% o/z s.r.(plain)	All died	..	..	..
2	11 wild	o s.r. o preferred but reversed by conditioning in 12 days	(*a*) 1 mg. s.r./z in 2-g. pill o (plain)	Fair, but o also eaten; none died	o/2	o s.r.	Preferred
			(*b*) 1% s.r./z o (plain)	All died	..	..	..
3	6 wild	s.r. 2 days	1, 5, and 10% s.r./z	5/6 ate in 40 min.; all died	..	..	..
4	6 wild	Wheat 2 days	As above	o/6 ate in 40 min.; 1 survivor	..	..	..
5	6 wild	s.r. 2 days	2, 5, and 10% s.r./z	All died	..	..	..
6	7 wild	Wheat 2 days	As above	2 survivors	..	..	..
7	12 wild	b 8 preferred, s.r. 2 preferred, 2 variable 11 days	(*a*) 1 mg. flour paste/z	All eaten; 4 died	2/4	b s.r.	Preference much as before
			(*b*) As above	Poor; 3 ate a little	o/2	b s.r.	Preference much as before
			(*c*) 5% b/z s.r.(plain)	5 died	2/9	b s.r.	Preferred by one Preferred by one Other varied
			(*d*) 5% b/z s.r.(plain)	1 died; all ate s.r.	o/4	b s.r.	Each preferred by one
			(*e*) 5% s.r./z b (plain)	Small takes; 1 died in 1 day, 1 in 5 days	..	..	..

TABLE 46 (*cont.*)

Experiment No.	*Number and kind of mice used*	*Preliminary feeding*	*Poison used*	*Acceptance of poison bait and its effect*	*Duration of illness/ days post-bait*	*Post-bait*	*Acceptance of postbait*
8	3 wild	Survivors of squill/s.r. test, $2\frac{1}{2}$ weeks' interval	(*a*) ? 1% s.r./sq.	2 survived 1 of which escaped	..	..	..
			(*b*) { 10% s.r./z s.r.(plain) bread mash	Survived, took most s.r.	..	..	..
		2 weeks' interval	(*c*) { Bread paste/sq. paste (plain)	Ate only plain	..	..	..
		$3\frac{1}{2}$ weeks' interval	(*d*) { 1% s.r./z o (plain)	Plain food only taken	1/4	{ s.r. o	s.r. refused at first but preferred after day 1
			(*e*) { 5% o/z s.r.(plain)	Ate both and died	..	..	..

Explanation of Table

A. The subheadings to each experiment (*a*, *b*, &c.) indicate successive poisonings.
B. Where foods are shown bracketed together, they were supplied simultaneously as a choice; where unbracketed they were given in succession.
C. Abbreviations: z = zinc phosphide; A = arsenious oxide; sq = water extract of red squill; o = dry rolled oats; s.r. = sausage-rusk mash; o.m. = rolled oats mash; b = crushed barley.

prebaiting has been used as a standard technique for clarifying the results.

Rzóska's direct observations on how mice approach poison bait confirm the results from the feeding activity charts. Even after fasting mice approach and eat poison bait intermittently and slowly. In experiment 1 (*a*), the only instance in which a fast (16 hrs.) was imposed, four tame mice each fed as many as 6–8 times to finish 1 g. of wet rusk with 1 mg. of zinc phosphide: three of them finished it in 11–22 minutes, and the other ate most of it in 32 minutes.

In experiment 7*a* a 0·25-g. pill (1 mg. zinc phosphide in flour paste) was eaten completely or partly after 1 hour by 3 out of 12 mice and after 3 hours by 3 more. By this time the other 6 had touched it little, if at all. However, all was finished in 12 hours.

4. APPROACH TO POISON BAIT WITH ALTERNATIVE PLAIN FOOD PRESENT

This should really be the crucial experiment for understanding the behaviour of mice in their natural environment towards poison baits laid for

them, and, if we can make any prediction from their behaviour to poison bait with no alternative food (circumstances weighted heavily against the mice), their tentative behaviour should enable a fair number of them to survive.

A single test by Rzóska is summarized in Table 46 (expt. 2). He first conditioned the mice to prefer moist sausage-rusk to dry rolled oats (by offering first a choice, then rusk alone for several days, then back to a choice again), and then offered them a choice between rusk with a small dose of poison (1 mg. zinc phosphide in 2 g. of rusk) and unpoisoned rolled oats. In spite of the conditioning and the small amount of poison only one mouse out of eleven ate the whole 2 g. of rusk (mean take per mouse was 1·3 g.), while all ate some of the plain bait (mean take 2·0 g. per mouse) which they had taken in small quantities before. No deaths were expected in this test, but the behaviour was clearly changed by the inclusion of the poison.

This whole question was subjected to a more searching analysis with the aid of the activity recording machine and the results of the experiments are summarized in Table 47. The four groups of experiments represent attempts to evaluate the different factors concerned step by step. In group (*a*) the mice were accustomed to feed from two sites, and the effect of offering poison in one of the sites only without changing the food was tested. We may envisage this sort of situation in the field, when a bait very like the 'natural' food has been chosen so that the mice are feeding at alternative sites only one of which will be poisoned. The results suggest that only those mice, which are already feeding to a considerable extent at the site to be poisoned, will take a lethal dose (in these experiments only the ones that took at least half of their daily consumption from the point concerned). The others, although they visited the poisoned sites all the night, as the activity charts show, nevertheless did not eat the poison bait (or only in minute quantities) but fed solely at the plain bait.

This result suggests that prebaiting in the field is of some use, though it also shows that there may be a number of mice that will only pay a small amount of attention to prebait, and their interest will not be sufficient to overcome their shyness of poison bait when it is substituted for the prebait.

The group of experiments placed under (*b*) are much the same as those under (*a*) except that the mice had been accustomed to feed at one site only and the poison was then provided at an extra site. The results show much the same proportion of lethal doses taken as under the first arrangement; therefore it is clear that some mice may be diverted from their normal food supply to take bait at a new site even though poisoned. These results of (*a*) and (*b*) seem to be mutually contradictory in that one supports the value of prebaiting, the other does not. The answer probably is that in any population of mice, to which baits of the same nature as their normal food are given, there will be some that take enough of the poison to die, some that would only take enough, if accustomed to the site by some day's prebaiting, and some that will visit only and take none.

TABLE 47. *Approach to poison bait with alternative food present*

Mice used	*Plain bait*	*Poison bait*	*Poison bait take/ last day's plain bait take at this site*	*Plain bait take/ last day's prebait at this site*	*Result*	*Survival time*
(*a*) Approach to an initial poison bait at an accustomed site with alternative plain food (same as poison base) also at an accustomed site						
♀ 20·5 g.	o	o/z 5%	< 0·1/0·3	3·6/3·2	Survived	..
♀ 22·5 g.			< 0·1/1·3	3·0/2·0	,,	..
♀ 21 g.			0·2/2·3	0·7/1·1	Died	3½ hrs.
♀ 20·5 g.	o	o/z 5%	0/0·6	3·3/2·6	Survived	No record
♀ 17·5 g.			0·1/1·3	0·7/1·4	Died	1 hr.
♀ 17 g.			0/0·1	3·3/3·1	Survived	..
(*b*) Approach to an initial poison bait at an unaccustomed site but in the accustomed bait base (same as prebait). Alternative plain food (also same as prebait) at the accustomed site						
			Poison bait take			
♀ 19 g.	o	o/z 5%	0·08 g.	3·1/3·5	Survived	..
♀ 25 g.			0·2	0·3/3·2	Died	2 hrs.
♀ 15 g.			0·13	1·7/3·4	Survived	..
♂ 23 g.	o	o/z 5%	0·04	3·8/3·9	Survived	..
♂ 15 g.			0·2	0·6/3·0	Died	No record
♂ 18·5 g.			0	3·1/3·0	Survived	..
(*c*) Approach to an initial poison bait at an unaccustomed site in an unaccustomed bait base. Alternative plain food (same as prebait) at the accustomed site						
♀ 11·5 g.	wh	o/z 5%	0·04 g.	2·5/3·2	Survived	..
♂ 20·5 g.			0·22	3·5/4·1	Died	7 hrs.
♂ 16 g.			0·14	3·0/4·0	,,	1 hr.
♂ 22·5 g.	wh	o/z 5%	0·5	1·6/6·0	,,	2½ hrs.
♂ 24 g.			0·18	1·7/6·0	,,	3½ hrs.
♀ 20 g.			0·78	3·0/4·9	,,	16 hrs.
(*d*) Approach to an initial poison bait at an accustomed site in a new bait base. Alternative plain food (same as prebait) present at a new site						
♂ 20 g.	wh	o/z 5%	0·1	0·4/5·0	Died	½ hr.
♀ 17 g.			0·27	0·5/3·9	,,	2 hrs.
♀ 17 g.			0·07	0·3/4·2	,,	½ hr.

Experiments under (*c*) and (*d*), however, present a different picture. Here the poison was offered in a food different from that to which they had been accustomed, and a much higher proportion (8 out of 9) took lethal doses. The presence of the accustomed food at the same time, whether in the old or a new site, did not seem to have much effect, even though in many of the instances quite large quantities were eaten as well as the poison bait. Furthermore, the times of survival shown by the activity charts are generally short and suggest that the mice ate the poison fairly quickly after it was offered.

We must needs conclude from these experiments, therefore, that the rolled oats base, in which the poison was offered, was preferred to the wheat diet on which they had been living before. This emphasizes the importance of choosing the right bait and supports the evidence already advanced in Chapter 7 to show that the food preference of different populations should be tested before poison bait is put down. Under such conditions it is quite possible that satisfactory results may be obtained by direct poisoning.

The general conclusions to be drawn from these experiments are not very clear-cut, but with house mice this is very rarely the case since there is so much individual and group variation in the behaviour. We may perhaps put our conclusions in this way: (1) where it is possible to find a bait which is preferred to the normal food supply it may be possible to get good results by poisoning, even without prebaiting; (2) where this is not possible (owing to diversity in the natural supplies, &c.) the mouse's tentative approach and diffuseness of feeding activity may prevent it, even after prebaiting, from taking a lethal dose of poison.

Finally, we should mention the evidence obtained from field experiments in a food store (Table 48, expts. 1, 2, 3, 5, 6, and 7). These results were mostly failures, even though prebait was taken in quite large quantities; usually on the day of poisoning some of the baits would be taken completely, many partially, and many left quite untouched. The nature of the habitat, with its large stacks of grain sacks, in which mice could live with abundant food all round them and with no compulsion to visit the margins, where the poison bait was placed (though a fair proportion did so, see Ch. 2), made it clear that initial poisonings could hardly be expected to reduce the populations drastically. Even so, the continual recovery of postbait levels to that of the prebait, in spite of obvious takes of poison bait, was very puzzling. When we watched during the first 2 hours after the poison bait was put down (expt. 7) in a flour stack we received the impression that visits to the bait were casual and must extend over a great part of the night, and that once a bait has been nibbled there is not much further decrease in that particular bait. Perhaps the counter-attraction of 'natural' food sites (which in a habitat like this are almost infinite in number) is too great to allow more than casual visits to the bait. This, combined with the tentative approach and general shyness which we observed in the recording machine experiments means that the mice will usually eat sublethal doses only.

In general we may say that, although there is no ability in mice to detect a poison bait as such without previous experience (hunger pressure ensured that lethal doses were *ultimately* eaten in the laboratory experiments), the feeding behaviour is such that even with prebaiting at an accustomed site the full effects of a first poison bait may be avoided by intermittent and sporadic visits and consequent 'sampling' (not of course conscious) of the bait. Thus, if a lethal dose is not eaten by the time that warning symptoms commence, the mouse will escape the more disastrous consequences.

TABLE 48. *Summary of field experiments*

Experiment No.	*Prebait and duration*	*Poison used*	*Acceptance of poison bait*	*Lag in postbait recovery/ duration of postbait*	*Postbait*	*Acceptance of postbait*
1	s.r. o.m. 8 days	(*a*) 10% o.m./z	? Moderate	0/6	s.r. o.m.	Back at once almost to previous level
		(*b*) 10% o.m./z	? Poor	0/6	s.r.	Back at once to previous level
		(*c*) 15% s.r./A	Poor	2/4	o.m.	Back to about half previous level
2	s.r. o.m. 8 days	(*a*) 10% o.m./z	? Moderate	2/6	s.r. o.m.	Increase to more than previous level
		(*b*) 15% o.m./A	Apparently good	1/5	s.r.	Back to same level
		(*c*) 15% s.r./A	Poor	0/5	o.m.	Back at once to previous level
3	o.m. s.r. 7 days	(*a*) 10% s.r./z	Apparently good	2/6	o.m. s.r.	Gradual recovery to three-quarters previous level
		(*b*) 15% s.r./A	Poor	2–5/13	o.m. s.r.	Gradual recovery to initial level
		(*c*) 1% s.r./sq	Apparently good	1/20	s.r. {o.m. {s.r.	Recovering to initial level; preference for s.r. when choice given
		(*d*) {2% s.r./z {1% o.m./sq	Poor	1/5	{o.m. {s.r.	Quick recovery, preference for s.r.
4	o.m. 10 days	(*a*) s.r./sq inside stack	?	0/8	o.m. s.r.	Inside baiting had no effect on take, which even rose
		(*b*) 10% s.r./z	Moderate	0/4	{o.m. {s.r.	Immediate recovery with slight preference for s.r.
		(*c*) {2% s.r./z {1% o.m./sq	Poor	1–2/7	{o.m. {s.r.	Recovery with preference for s.r.
5	s.r. 18 days	(*a*) 2·5% s.r./sq	Apparently moderate	0/9	s.r.	Recovery at once
		(*b*) 10% s.r./A	,,	2–3/21	s.r.	Slight delay in recovery, but to higher level
		(*c*) 2% s.r./z	Apparently good	1/5	s.r.	Almost immediate recovery to previous level
6	s.r. 18 days	(*a*) 2·5% s.r./sq	,,	0/9	s.r.	Recovery at once
		(*b*) 10% s.r./A	,,	2–7/25	s.r.	Drop at once and rise to previous level, then to normal after 7 days
		(*c*) 2% s.r./z	Fair	0/5	s.r.	Recovery at once
7	s.r. 8 days	(*a*) 5% s.r./z	Poor	1/10	s.r. s.r.+ 2% NaCl	Back to 3/5 in 3 days, then back to initial level on day 8
		(*b*) 1·3% s.r./z + 2% NaCl	Poor	0/2	s.r.	Back at once to half previous level

N.B.—Conventions and abbreviations as in Table 46.

5. POSTBAIT BEHAVIOUR AFTER INITIAL POISON TESTS

(*a*) **Experimental evidence** (acceptance, Table 46, expts. 1*b*, 2, 7*c*, 7*d*, 8*d*; avoidance, Table 46, expts. 1*a* and 8*d*).

Survivors of initial poison tests were offered a choice of the food in which the poison had just been given and a different food. We should probably give more weight to instances where definite illness had occurred, but, even where this was absent, the choice is important, because the mice must have had some 'experience' of the poison bait in order to avoid it (see previous section).

In experiment 2*a* after a sublethal dose of poison all the mice immediately chose the same base in which poison had been given; however, there was no illness. In experiment 1*b* a similar preference was shown, although the mice had just avoided poison offered in this base. In the previous poisoning (1*a*) where definite illness occurred, they had avoided the food in which the poison was offered at first, but changed back within a few days of the start of post-baiting. Similarly, in 8*d* the 'experienced' base was completely avoided for one day and then preferred by the third day.

These last two instances show the sudden changes which we have so often observed in individual mice and which obscure results in work of this kind. We can make the broad inference that mice may either accept an 'experienced' base at once, or, if they are shy, they regain confidence in a day or so. The following experiment, however, shows how difficult it is to draw general conclusions about the subject. In Table 46, experiments 7*c* and *d*, are summarized the preferences of four mice which had survived two sublethal doses of zinc phosphide in a 'neutral' base and one exposure to poison in one of the bases (crushed barley) used as food throughout the experiment. The tabular summary can only hint at the whole story which is as follows.

The poison offered (7*c*) was 5% zinc phosphide in crushed barley with plain sausage-rusk mash as an alternative. The survivors (3 out of 8) all took very small amounts of the poison bait and fair amounts (1–2 g.) of the plain food. One mouse, which had throughout the experiment preferred wet rusk to crushed barley, recovered to a normal take at once and continued with a firm preference for rusk. The other two mice fed little the first day of the postbait, but recovered after that. One, which had preferred crushed barley previously, now showed a slight preference for sausage-rusk mash, but this was reversed again after 5 days; the other mouse which had had no particular preference for either food, at once showed a marked preference for crushed barley, the food in which the poison had been offered, and this continued throughout the postbait.

The behaviour of the first two mice is in accordance with the general conclusions reached, but that of the third is quite extraordinary and difficult to explain. It emphasized the importance of individual tendencies

among mice and confirms the difficulty of seeking a standard poisoning method to give consistent success.

The two experiments 1*a* and 8*d* show mice definitely avoiding sausage-rusk mash after they had experienced it with zinc phosphide. The avoidance, however, was temporary and was overcome in one instance without any interference on our part (the second survivor in 7*a* (see above) behaved similarly) and in the other instance by offering sausage-rusk mash alone for 2 days. The shyness was real and not caused by illness because alternative food was eaten.

The above facts prove the ability of house mice to detect and discard an experienced food base, but this shyness was more or less transient. They are doubtless helped in recognizing the harmless nature of the plain base by their intermittent feeding habits.

(*b*) **Field evidence** (Table 48, expts. 3*c*, 4 *b* and *c*, 5 *a*, *b*, and *c*, 6 *a*, *b*, and *c*, 7*a*).

The earlier tests in the oat and flour stacks at the buffer depot were conducted so as to avoid even the possibility of any shyness of the plain bait arising. Thus we changed the bait base after poisoning (sausage-rusk mash to rolled oats mash and vice versa). When it became clear that the tests were generally unsuccessful, we designed experiments to analyse the behaviour of the mice more minutely. In some of the experiments, where midway through the postbait we changed back to the food in which poison had been offered (1*a*, 2*a*, 3 *a* and *b*), we noticed no significant fall. Therefore it was clear that at this time (the change in each case was made about the fifth day of the postbait) no shyness of the bait base remained.

In later experiments we offered the same base immediately after using it for poisoning. The consequences differed; either the postbait returned at once (within 2 days) to the level of the prebait (3*c*, 4 *b* and *c*, 5 *a* and *c*, 6 *a* and *c*), or it started quite low and gradually recovered over about a week to or near to the original level (5*b*, 6*b*).

The first result shows no shyness of the bait base. The second class of results needs more discussion. The possibilities are:

(*a*) That the gradual rise is due to recovery from illness or to reinvasion. Plaster of Paris patches revealed how many baits were being visited as distinct from being eaten. The result in experiment 3*b* was in detail as follows.

TABLE 49. *Overcoming of shyness after poison baiting*

Day of postbait:	*2 and 3*	*4*	*5*	*6*	*7*	*8*	*9 and 10*	*11*	*12*
Points from which bait was taken .	7	6	11	20	20	22	33	30	34
Points visited only .	22	20	13	11	10	6	4	6	2
Points negative .	9	11	12	9	8	10	1	1	1
Total . . .	38	37	36	40	38	38	38	37	37

It is impossible to show conclusively that illness or reinvasion was not responsible for the gradual rise in the baits eaten contrasted with the decrease in the baits visited. But it seems unlikely that ill animals should go as far as to the outskirts of a big stack and it is not clear why reinvasion should happen just at that moment. Plaster of Paris between some stacks revealed little intercommunication.

(*b*) Another possible explanation is of course that the delay in recovery of the postbait may be due to the mice overcoming their shyness of the food. In view of the laboratory results we must admit that this may on occasions play a small part, but in the result given above the postbait was not in fact the same as the base in which the poison was offered.

(*c*) Such a result might be, however, due to a generalized bait-shyness after experiencing poison. Such an interpretation is not supported by the experimental evidence, but it is hardly fair to compare circumstances in which a mouse is confined in a small cage and has the two choices of food under its nose the whole time with conditions in a food store. Loss of interest in bait (as food) was found in some experiments, described elsewhere (see Ch. 7). There is also the additional fact that the shyness lasts for longer or shorter periods according to the kind of poison used (e.g. after arsenic recovery is slow). This again is not reflected in the laboratory experiments simply because arsenic was not used in them. Table 48 shows the correlation between long shyness of the postbait and the use of arsenious oxide. This behaviour is obviously determined by the poison experience and not by the type of postbait since it occurs whether a new or the experienced food is offered after poisoning.

We must conclude that the house mouse shows no inevitable permanent shyness of the food in which it has tasted poison. There is general bait-shyness, and in some cases avoidance of the postbait for a short while. The mouse probably recognizes plain food again by 'sample take' and so, unless really ill, will quickly be eating its normal amount again.

6. SUBSEQUENT POISONINGS AND THEIR EFFECTS

(*a*) Approach to subsequent identical poison baits

(i) *Experimental evidence* (Table 46, expts. 1*b*, 2*b*, 7 *b* and *d*, 8*c*)

There was only one clear case of acceptance in experiment 2*b*, where a second identical poison bait was offered 3 days after the first one; the effect was fatal. The first dose seemed to have no effect; the second and fatal dose was eaten in small but sufficient amounts, and there was also a drop in the amount of alternative plain food eaten compared with the first test, presumably because the onset of warning symptoms limited the time available.

In 7*d* one of the three surviving mice nibbled the second poison bait and died. The poison take was very small, and the amount of alternative food eaten was considerable.

Mice refused a second identical poison bait in the following instances. In experiment 1*b* four mice refused a bait in the presence of other food 9 days after accepting a sublethal dose. In experiment 8*c* a single mouse after an experience some weeks before completely refused a second bait of bread paste with red squill extract in the presence of plain food. In the experiment 7*b* a general avoidance of a second sublethal dose with no alternative food occurred; two mice ate a little, another left tooth-marks on the poison bait; the rest recognized it and ate none. Four of the mice carried the poison bait into their cover boxes. Later in the same experiment (7*d*) a second poison bait was detected by two out of three mice; the third ate an insignificant amount and died. All three ate considerable amounts of alternative food.

(ii) *Field evidence* (Table 48, expts. 1*b*, 3*d*, and 4*c*)

Only failures, and therefore probably refusals of most or all of the poison bait, were recorded in the field experiments. These may be considered as being done in the presence of only too abundant alternative food. In experiment 1*b* an exactly similar bait (wet rusk /10% zinc phosphide) was offered twice within 7 days. The first time the amount taken was moderate (see Table 50 for figures) and the postbait rose immediately but not to the previous level; the second time much the same amount was eaten, but the postbait went back immediately to the same level as before.

TABLE 50. *Results of poisoning a second time with the same poison.*

Expt. No.	*No. baits taken (first poisoning)*	*No. baits taken (second poisoning)*
1 *a* and *b*	17	14
3 *a* and *d*	40	15
4 *b* and *c*	29	10
*3 *c* and *d*	33	15
*2 *b* and *c*	42	9

* In these experiments the base was changed.

In experiment 3*d* rusk/10% zinc phosphide was offered first with apparently good effects and the postbait rose in 5 days to about two-thirds of the previous level. After one or two trials with other poisons a choice of poison baits was given, one being rolled oats mash/1% squill (water extract), the other the same as the first except that the concentration of zinc phosphide was reduced to 2%. Very little of either was eaten and the postbait rose immediately to the same level as before. The squill bait was even less well taken than the zinc phosphide, but though this suggests the mice were not shy of the experienced poison, the result is too poor for us to take this comparison seriously.

Experiment 4*c* was on similar lines and showed a similarly striking drop in the number of baits eaten at the second poisoning.

Finally we will quote a corn-rick experiment. A large wheat-rick, riddled with mice, was baited with wet rusk/10% zinc phosphide twice, the first time about 3 weeks before threshing, the second time 2 days before.

At threshing the following results were obtained:

No. killed from first poisoning. . .	415
No. killed from second poisoning . .	40
No. of live mice left	*c.* 400
Total	855

The first poisoning therefore killed just under 50% of the mice, whereas the second one only killed just over 10%. This result may be considered a fairly good measure of the effect of 'poison-shyness'.

We may conclude, therefore, that a second identical poison bait is less likely to be eaten than the first; in experimental conditions some mice quite clearly detected and rejected a second bait.

(*b*) Postbait behaviour after repeated poisonings towards experienced and new foods

(i) *Experienced food*

During a succession of poison baitings mice appear to come back to the plain postbait with less and less shyness.

Experimental evidence (Table 46, expts. 1*b* and 7*d*). The first experiment shows typically what happens; after a first poison bait of wet rusk/zinc phosphide the choice of postbait wavered for a few days between dry rolled oats and rusk and preference for the latter was re-established by giving it alone. After a second identical poison bait, very little of which was eaten, postbait recovery was immediate and rusk was preferred straight away.

In experiment 7*d* two consecutive poison baits (crushed barley/zinc phosphide) with plain rusk as alternative food were each followed by a postbait choice of crushed barley and rusk. On the second occasion two survivors were left; one, who had preferred crushed barley previously, switched to rusk during the poison night, and then immediately back to crushed barley at the same level as before. The other mouse preferred rusk throughout, but continued to take a minor amount of crushed barley (*c.* 1 g. daily) at a steady level except on the night when poison was mixed with it.

Field evidence (Table 48, expt. 3*d*). This experiment is not quite so clear, but the complications are probably not important (see Table 48 for details). After being offered a second poison bait of rusk/zinc phosphide the mice were given for postbait a choice of rusk and wet rolled oats, and clearly preferred the former in which the poison had been offered. They immediately ate the full amount.

We may conclude that the shyness of an experienced bait in the later phases of a campaign passes quickly, if it exists at all.

(ii) *New food*

Experimental evidence (Table 46, expts. 1 *a* and *b*, 2*a*). Most of this evidence is complementary to the discussion on postbait behaviour to food associated with poison bait and has been indirectly mentioned before. It is enough to say that in only one case (1*a*) was a new food clearly preferred to the 'experienced' one, and then the shyness was easily overcome.

Field evidence. (Table 48, expts. 1*a*, 2*a*, 3 *a*, *b*, and *c*, 4 *a* and *b*). Two methods were used in the field experiments to test whether a new bait is more eagerly accepted than the one in which poison has just been offered. Two foods, one being the poison base, were offered, either consecutively to note any change in the level of consumption, or simultaneously to note the preference.

In the first alternative wet rusk and wet rolled oats were used interchangeably, and we usually changed from one to the other about the fifth day of postbaiting, when mice had recovered from any shyness due to the poison. In experiments 1*a*, 2*a*, and 3*a* the mice ate more of the bait in which the poison had been offered; in experiments 3*b* and 4*a* they showed no significant preference.

In the second method when mice returned at once to the plain bait after poisoning, they preferred (3*c*, 4*b*) the base in which the poison had been offered as compared with the new food. Conversely, when mice avoided the postbait for some days, they did this more frequently when a new food was offered (1*c*, 2*a*, 3 *a* and *b*) than when the poison base was given (5*b*, 6*b*).

We may conclude that changing the bait after poisoning has little or no significance for house mice.

(*c*) Approach to subsequent different poison bait

(i) *Same bait, new poison* (Table 46, expts. 8*b*; Table 48, expts. 2*b*, 3 *b* and *c*, 5 *a*, *b*, and *c*, 6 *a*, *b*, and *c*)

There is only one minor laboratory experiment under this head, and it is not worth considering in detail. A survivor from a test with rusk/squill (water extract) was offered a choice of rusk/10% zinc phosphide and rusk plain. It avoided the poison and again survived.

The evidence of *field experiments* is again difficult to interpret; the only method is to consider in each case the apparent take of poison bait, disregarding the fact that all of these trials were failures. We must assume that a marked change in approach would be detectable even by the inadequate criterion of poison bait taken.

Table 51 shows the number of baits taken wholly or partly in experiments where arsenious oxide followed zinc phosphide in the same base or vice versa. The interval of time was 6–10 days and the total of baits was the same throughout each experiment.

TABLE 51. *Number of baits taken in successive poisonings with zinc phosphide and arsenic*

Expt. No.	*Zinc phosphide baits taken*	*Arsenious oxide baits taken*	*Zinc phosphide baits taken*
2 *a* and *b*	24	42	..
3 *a* and *b*	40	16	..
5 *b* and *c*	..	20	34
6 *b* and *c*	..	41	23

Other results involving successive baitings with water extract of squill and arsenious oxide are as follows:

TABLE 52. *Number of baits taken in successive poisonings with arsenic and red squill*

Expt. No.	*Squill baits taken*	*Arsenious oxide baits taken*	*Squill baits taken*
3 *b* and *c*	..	16	33
5 *a* and *b*	22	20	..
6 *a* and *b*	35	41	..

These results may be compared with Table 50 showing the successive takes of baits containing the same poison.

Another field experiment in Oxford is given here as collateral evidence. The course of most field experiments does not help greatly in comparing reactions to different sequences of baits and poisons because the environments vary so widely. Hence the buffer depot experiments done in units which were strictly comparable and designed to throw light on these problems compose practically all the field evidence.

This experiment was carried out in the basement of a large building where there was little food for the mice. Prebaiting was done with dry rolled oats and a peak of nearly 130 g. was obtained. Poisoning with rolled oats/1% zinc phosphide killed most of the mice (10 g. of poison bait was eaten) and over 5 days the postbait (rolled oats again) rose to 16 g. only. After a second poisoning with rolled oats/10% arsenious oxide (2·5 g. eaten) the postbait was untouched for 5 days. If the poison bait taken is expressed as a percentage of the prebait peak, the figures for the first and second poisoning are 8% and 15% respectively. In this case therefore the second poisoning was made even more successful than the first by means of changing the poison and not the bait.

From these data it is clear that a change of poison, but not of base, ensures a take, which may be as good as or better than in a first trial. The single laboratory result shows that individual behaviour has nevertheless to be reckoned with. The general failure of the field experiments also confirms this.

(ii) *New bait, same poison*

Experimental evidence (Table 46, expts. 1*c*, 7 *c* and *e*, 8*e*). Two of these experiments (1*c* and 8*e*) consisted in offering dry rolled oats/5% zinc phosphide to mice which had survived a previous poison bait of wet rusk/zinc phosphide. Alternative plain food (wet rusk) was provided. In each case all the mice died.

In 7*c* crushed barley/5% zinc phosphide was offered with alternative plain food not used as poison base before, to the survivors of two doses of flour paste/zinc phosphide. Five out of eight mice were killed.

In 7*e* rolled oats/5% zinc phosphide was given with alternative food (not used as poison base before) after two doses of crushed barley/zinc phosphide. Both mice died.

Field evidence (Table 48, expts. 2 *b* and *c*, 3 *c* and *d*). In the first of these experiments arsenious oxide was offered in wet rusk after having been offered in wet rolled oats; in the second red squill extract was offered in wet rolled oats after rusk. In both these cases there was a considerable diminution in take (42:9 and 35:15). We should add that in experiments 3 *c* and *d* two poisons, both used previously, were offered as a choice, one in a known, the other in a new base. Of the latter only nine baits were taken, of the experienced base fifteen.

The laboratory and field results apparently conflict, since the former point to success as a result of changing the base. We must remember, however, that in all the laboratory experiments the new base was one which had been used as plain food or as poison base previously during the experiment and was the only alternative food. Therefore, although under the simplified conditions imposed by laboratory experimentation change of base makes for success in a poison trial, this does not follow in natural conditions where alternative accustomed food is abundant and varied.

(iii) *New bait, new poison* (Table 48, expt. 1*c*)

Only one *field experiment* of this series bears upon this. Wet rusk/15% arsenious oxide followed wet rolled oats/zinc phosphide. The total of baits taken was fourteen in the first trial and ten in the second. This result is inconclusive, but does not contradict the probability that a new poison in a new base will be at least as successful as a new poison in an experienced base.

Two small-scale field trials carried out by Miss Laurie are given as collateral evidence. Both were minor infestations in private houses, involving not more than one or two mice. In one case bread and milk was used as prebait to unsuccessful poisoning with 10% arsenious oxide followed by dry rolled oats and successful poisoning with 10% zinc phosphide. In the other case exactly the reverse happened. Here the change to a new poison and a new base made the whole difference between failure and success.

On the whole, therefore, it seems that a change of bait is less important than a change of poison. There seems to be no clear-cut or lasting 'bait shyness', but rather a generalized suspicion of *all* baits, which is exaggerated after using arsenious oxide. Otherwise such suspicion is quickly overcome (in about 2 days) and mice are often found actually to prefer the bait in which they have just been offered poison. This quick overcoming of shyness may be facilitated by their method of feeding, which is to take very frequent tiny fragments of the bait. In this way they have ample opportunity to 'sample' the bait and discover by the presence or absence of warning symptoms (which develop nearly as quickly after a sublethal as after a lethal dose) whether the bait is harmless.

10

CONTROL OF HOUSE MICE BY POISON IN FAVOURABLE ENVIRONMENTS

1. WHAT IS A FAVOURABLE ENVIRONMENT?

We cannot hope to control house mice by quite so simple a routine as we can rats. In the first place we have to decide between trapping and poisoning; generally this is a question of magnitude. Houses and shops that have a few mice and will not need more than 20–30 traps set for about 3 days may just as well be done by this method, especially if occupiers can be persuaded to do the job themselves, stimulated by the loan of traps. But when a paid hand is employed traps quickly become uneconomic, especially if a big block of premises needs treating.

If we decide to use poison, then we must know some details about the topography of the infestation and the density of the mice. If it proves to be an 'easy' infestation (one in which food is lacking or is separated by some distance from cover), then it may be worth trying direct poison baiting without bothering about prebaiting. If it is a difficult infestation, then it may be necessary to allow for a second treatment as well as using prebait, and the sequence of poisons must be decided.

There are three methods of determining into which class a particular infestation falls, various combinations of which can be used simultaneously, so that one checks the other.

(1) *Inspection.* This should always be carried out with great care and should not neglect *any* part of the premises concerned. The main headings under which we can gather information are the numbers and distribution of traces and the amount, quality, and disposition of the food supplies. Traces consist of obvious trade-marks like droppings, damage to foods and fabrics, and mouse holes together with the less obvious signs such as patches of wet urine, smears from the fur on objects that the mice are constantly passing over, mouse smell, &c. Particular attention should be paid to the freshness of such traces: if the premises have not been cleaned lately large collections of droppings remain and may give a misleading impression of abundant mice, when in fact only a few remain. Since droppings harden in about 48 hours and also darken considerably in colour, those that are fresh can readily be detected by pressing them with a pencil or by noting the colour. Damage to food is often identifiable as fresh, but appearances can be misleading even here. Patches of wet urine are the best evidence that mice have been in the neighbourhood very recently. On the contrary, mouse holes and smears help very little unless the holes are obviously fresh gnawed,

and such signs should be used mainly as collateral evidence when sizing up the infestation as a whole.

The best places to search for mouse traces are those where the mice would linger, i.e. where there is food and/or cover. Thus we must first inspect high shelves, cupboards, drawers, and so on, and for this a good torch is indispensable. Then any cover, temporary such as sacks, boxes, and so on, or more permanent, such as furniture, placed against walls, should be pulled aside and the crannies behind them examined.

The routes that the mice follow are not so easy to trace directly, since they will be moving along these quickly and will leave little signs of their passage. However, we can usually infer which way they must travel, especially if we remember that mice will invariably follow along the side of walls or other perpendicular surfaces. Unless mice are known to be living in a room, they must enter at some definite place or places, and sufficient searching must discover these.

The distribution of the food supply is obviously important and no inspection would be complete without a complete survey of this. Not only will this control the movements of the mice and consequently the possibilities of intercepting them with baits, but we may get some idea of the kind of bait which they will prefer. Finally, we must emphasize the small amount of food that can sustain a large population of mice. Nothing is more striking than the persistent way in which mice appear in premises which at first sight seem to have no food at all to attract them. As many as twenty mice could live on about 3 oz. of food per day, and it does not need many lunch scraps or carelessly scattered crumbs to make up this quantity. Thus, if careful search reveals no source of food for mice, they may well be living on scraps daily imported by employees.

(2) *Testing for traces.* Where there is any doubt about the way in which mice enter a room or a building (e.g. where a previous heavy infestation has left many holes and abundant droppings), or about their routes over a certain area, we can seek enlightenment by placing at strategic points patches of white powder (gypsum or plaster of Paris) with the surface smoothed over. Such places will be around holes or along walls, where the mice are suspected of running. The main objection to this method is that it only achieves the same objects as the prebaiting technique described in Chapter 8 and does not have any attraction to the mice. Furthermore, it is untidy to clear up and so the procedure is not welcomed in some places. On the other hand, it is useful for discovering whether any other pest is removing bait, e.g. rats or even cockroaches. However, in such cases we usually have some suspicion as to what is happening beforehand, and the laying of patches serves rather for confirmation than for discovery.

Another disadvantage of plaster of Paris patches is that beyond a certain point it gives no quantitative information about the number of mice in a building. After a few mice have run over it such a patch is generally well

ploughed up, and further traffic will not alter its appearance. When we consider the sporadic feeding habits of mice (see Ch. 6) we realize that a single one would very quickly obliterate the surface of a patch placed on a runway. For certain purposes of research, however, plaster of Paris patches are indispensable (e.g. for determining whether mice are visiting baits but not feeding from them).

(3) *Prebaiting*. The procedure recommended by the Bureau has already been described and discussed in Chapter 8. This method has the advantage of achieving the same object as trace-testing, while at the same time securing whatever is possible of a true prebaiting effect (accustoming the mice to the type and position of the bait and drawing them in where possible). We may repeat that the great advantage of this method is the ease with which movements and distribution of the mice can be traced, while at the same time they are being prepared for the laying of the poison. Suppose that a room is being entered by mice from a point which is unknown and we want to find the best place to put the poison bait so as to attract their attention immediately. The use of plaster of Paris patches would probably show that certain runways were being used and that searching activity was dispersed all over the room. If, however, twenty or thirty small piles of rolled oats are placed at random around the room, this has the effect of stopping the searching of the mice to a greater or less degree, since they are presented at once with the object of their search. Activity will be damped down with the result that the picture of their movements and the main points from which they emerge will be more clearly discernible. This principle has been referred to so often in preceding chapters that it may seem unnecessary to labour it further. However, the correct siting of baits is so important for house mice that a final illustration is given here from work done by Elton. The experiment concerned has already been described in Chapter 2, but the results as given in Fig. 15 show more clearly the type of information we can derive from studying the distribution of baits taken. The figure shows the number of bait points placed around the room in question, and each is denoted by a sign indicating the day when it disappeared. It is obvious how baiting curtails the foraging of the mice: the baits are eaten from two well-defined focal points, one along the west side of the room, the other around the north-east corner, and these focuses spread from day to day like ripples as the baits are eaten up. In such a case we may reasonably conclude that mice are either entering or living at two main points in the room, and that if we concentrate the baits at these points we shall have the greatest chance of intercepting them and ensuring that a lethal dose of poison bait is taken.

The practical methods used in this kind of baiting are worth some consideration. A baiting tin saves much time. Most of the Bureau's experiments were done with the aid of bait tins, which would hold about 8 oz. of rolled oats, enough for laying over 200 bait points of about 1 g. each (enough to

cover a halfpenny). Into the lid of each tin a tapering spout about 3 in. long and in diameter about 1 in. at the base and $\frac{1}{2}$ in. at the end was soldered near the circumference so that the bait could be shaken out in easily controlled amounts. Usually we placed the bait piles directly on the floor, but when special tidiness was demanded we used cardboard slips.

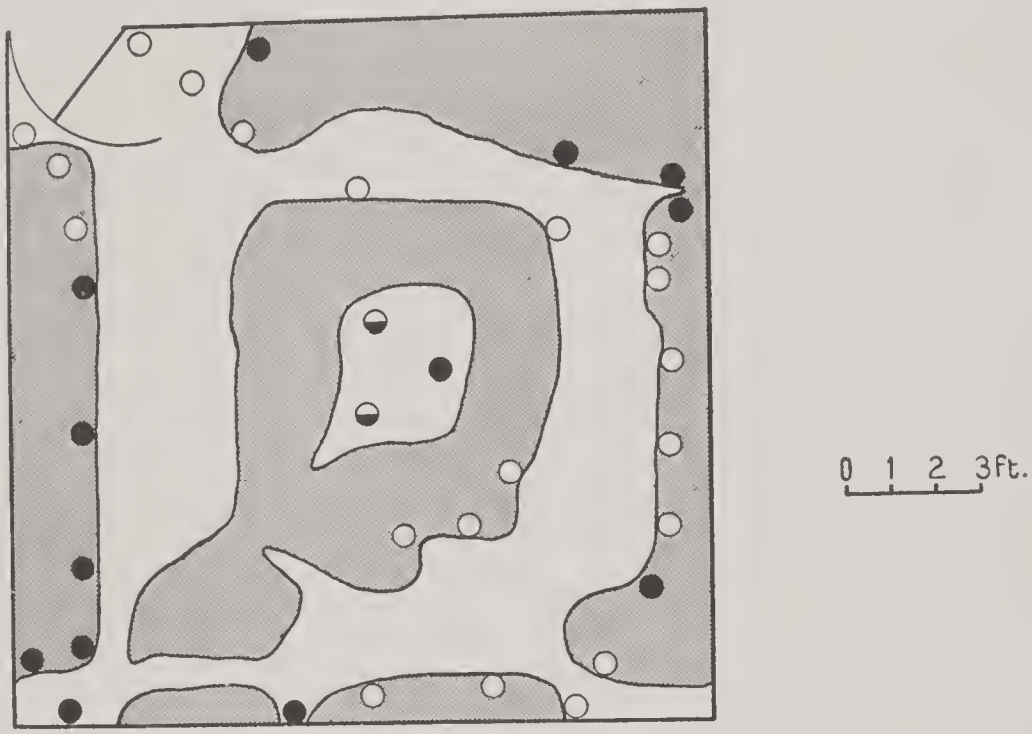


FIG. 15. Order in which bait piles were eaten in a storeroom. Shaded areas are stacked goods.

● eaten on day 1; ○ eaten on day 2; ◒ eaten on day 3.

By baiting consistently throughout in units of this kind a check can be kept on the total amount taken simply by counting the eaten bait piles. Wherever a focus of activity is discovered and the amount of bait at this point is increased to engross more and more of the attention of the mice, it is tempting to increase the size of the piles. However, the same effect is obtained if the *number* of small piles is multiplied, and, since mice usually finish one pile before going on to another, an approximate quantitative estimate of the total bait taken can be made without the bother of weighing all the bait piles.

When we needed more accurate information about bait take we used the following method. A weighed quantity of bait was first placed in the baiting tin, and the whole of this distributed, or, if this proved far too much, what remained in the tin was weighed after the baiting was done. The next day all the residual bait was collected in a bag, and fresh bait put down in the same way as on the first day. Thus accurate weighing of the total amount taken was possible, while the more approximate counts of the bait piles gave the topographical distribution of the take. With this method we used small bait trays or slips of cardboard.

The actual amount of bait placed in each pile is immaterial so long as the standard quantity is adhered to. It is best, however, to keep the amount small ($\frac{1}{2}$–1 g.), since this gives a finer reckoning of the total take.

For laying moist bait such as sausage-rusk mash we constructed a simple baiting tool which saved much time and ensured that the baits were fairly uniform. All that is needed is a tube about 12 in. long and about $\frac{1}{2}$–$\frac{3}{4}$ in. in diameter in which slides a rod with a plunger fitting the inside of the tube as exactly as possible. At the top end this movable rod is fitted with a spring, which in the resting position will carry the plunger upwards about an inch from the bottom of the tube. To fill this with bait it is only necessary to push the tube into a tin of sausage-rusk and the cylinder so formed is forced out by compressing the spring at the top of the tube. In this way many hundreds of baits can be laid in a short time, and by fitting a simple stop the length of the bait cylinder formed can be varied according to the amount required. The ones we used gave a bait weighing from 3–3·5 g.

In using a baiting tool of this type the sausage-rusk should not be rammed into the tube too tightly, or a compact bait will be produced which a mouse can carry away, and this makes the estimating of take rather a hazardous business. With a little practice it is possible to produce baits of just the right consistency, so that they will crumble when the mouse eats them, but will hang together satisfactorily when they are being laid.

Of course by using such an instrument it is possible and often attractive to slip baits into a position from which they cannot be recovered. This is not advisable, even with plain bait, since it needs to be collected up carefully before poison bait is put down.

2. DIRECT POISONING

Once the nature of an infestation has been discovered and we have decided to use poison, we must determine whether to use direct poisoning or whether to prebait first. Let us recall that this chapter is dealing only with favourable environments where the mice are hungry or easy to intercept. The question of whether to use direct poison baiting only arises under such circumstances. In all the more difficult environments, prebaiting is almost indispensable. However, in so many cases it is only possible to recognize that a particular infestation is classifiable as 'favourable' by carrying out trace-testing or prebaiting in the first place that direct poisoning can only be recommended as a trustworthy procedure in relatively few instances. Of course, where labour is scarce and there is a large amount of ground to be covered, direct poisoning will produce some results and is undoubtedly worth trying if the alternative is having to neglect some or all of the infestation.

The following are the places in which direct poisoning may well succeed: (1) any large buildings, such as food stores, that have been cleared of their contents so that the mice are left without food; (2) cold stores under the

same circumstances; (3) places where the normal food supply of the mice can be proofed against them (either by putting the food in containers, or by removing crumbs and scraps); (4) places where the cover of the mice is obviously disconnected from the food; and (5) corn-ricks.

Experiments by the Bureau to test direct poisoning have been few for the simple reason that we have always found prebaiting the most satisfactory way of assessing a population before and after poisoning. However, a certain number of trials have been designed, using other (though less satisfactory) methods of checking the numbers or proportion killed.

No. 1. Museum store shed. This was a small-scale test of direct baiting with zinc phosphide in dry rolled oats. The shed is about 12×9 ft. and contains miscellaneous equipment providing excellent cover but no food. It had been carefully made mouse-proof. Cages of wild house mice, forming a stock for experiments, were installed here and during some months about 12–20 mice escaped and established themselves in the hut, living on spilled food from the cages.

This spilled food was carefully swept up and four tin lids containing rolled oats with 5% zinc phosphide were placed. The previous day eight patches of plaster of Paris were put down and smoothed: each showed abundant footmarks and was smoothed again when the poison was placed. The next day 3 g. of the poison bait had gone and all the patches again showed footmarks. The next day the number of footprints had declined sharply, and only three patches had been disturbed. After this three more mice were involuntarily liberated, and the footprint index increased again. The poison was left down and after 2 more days the footprint index declined to nil and remained negative for 5 days, after which the experiment was discontinued. The poison was weighed again and a further 0·5 g. had been taken.

This preliminary experiment indicated that complete clearance was possible with direct zinc phosphide poisoning in rolled oats, where food was almost entirely lacking. It also showed that not all the mice took a lethal dose on the first night of poisoning, though the actual time taken to clear the initial population was obscured by the other mice that accidentally escaped.

No. 2. M.O.F. buffer depot, Oxford. This depot had five large rooms which had been almost full of sacked oats. As a fairly dense mouse population had damaged the oats badly, the stacks were all broken down and the oats resacked and removed. Most of the mice were caught by surrounding the stacks with shrimp netting, but a fair number escaped which were living in the walls.

On one floor a stack of sacked vetch seed about 15×15 ft. and about 8 ft. high, was left and many of the mice had taken cover in here and were pulling holes in the sacks for nesting material, though there was no sign at all of their having eaten any of the vetch seed. Throughout the building there

was still a certain amount of oats lodged in cracks between the floorboards, but this did not amount to much and the mice must have been hungry because the only other stores left in the depot were sacks of sugar, which they did not touch.

Arrangements were made for a trap census to be made before and after poisoning. The caretaker had 64 'Little Nipper' break-back traps baited with flour placed round the stack of vetch seed, and had been catching about three mice a day. These catches were recorded for 4 days before poisoning, and the total was twelve mice. Then 180 points (4–6 g. each) of sausage-rusk (1 part : 2 water by weight) with 3% zinc phosphide were placed in the crevices between the sacks. The day after poisoning four corpses were picked up: three days after, three more corpses were found and the poison bait was removed. In this case the bait points were all numbered clearly with coloured chalk, so that none should be missed.

The second trap census was then started: the same number of traps and the same bait were used and the catches recorded for 10 consecutive days: the total caught during these 10 days was three mice. Thus the average rate of catching before poisoning was three mice per day and after poisoning 0·3 mice per day. This is not a very satisfactory index, but showed that a very good kill had been obtained. It should be noted that the trap census before poisoning came at the end of 2 or 3 months' continuous trapping, so that the figures were not magnified by the usual high rate of catching when traps are first set.

This experiment showed that successful results can be obtained on a large scale by direct poisoning with zinc phosphide in sausage-rusk when a food store has been cleared of its contents. The density of baits used (*c.* 8 per sq. yd.) was high because the stack gave extensive cover in three dimensions. This was probably not too dense, because nearly a third of them showed signs of disturbance by nibbling.

Another point to notice is that corpses were picked up not only on the first day after poisoning, but for at least another day. Some of these may have had a small amount of poison and taken more than 24 hours to die, but it is at least as likely that these mice ate the poison bait on the second night after it was laid. Probably it would always be advantageous in direct poisoning to leave the bait down for 2 days unless conditions are such that the bait becomes unpalatable in a shorter time (e.g. drying up in hot weather). This contention is also supported by the results of experiments in direct poisoning with zinc phosphide in corn-ricks (see Ch. 13). Dead mice continue to drop out of a rick for at least 48 hours after the poison is laid, and sometimes longer.

Both these experiments are examples of direct poisoning employed in places where there is practically no food for the mice, and their hunger relieves us of the labour of prebaiting.

No. 3. Warehouse of the Port of London Authority. This experiment was

carried out by J. S. Watson and J. S. Perry. One floor of the warehouse, which was about 100 ft. long, contained tins of hard 'welfare' biscuits, a number of which had been damaged and stacked separately against one wall of one of the rooms. In this stack there were abundant signs of mice; droppings were all over and many biscuits that had leaked out of the damaged tins had the inner part eaten away (the outside of Welfare biscuits is too hard even for mice!). The rest of this room contained undamaged tins with no signs of mice, but in the two rooms adjoining there were a few damaged tins and some signs of mice though considerably less than in the main room. (For a plan of these premises see Fig. 4 in Ch. 2.)

As a preliminary a choice test was done with three baits: oatmeal, sugar-meal (national flour with 10% castor sugar), and sausage-rusk moistened with its own weight of water. Oatmeal was not at all liked and about equal quantities of sugar-meal and moist rusk were taken, indicating a preference for the former. After this baiting was done with sugar-meal for 3 days in the main room only. Twenty baits of 10 g. each were put down and after 2 days 40 g. of this had been taken (mean 20 g. per day); on the third day 18 g. were taken. All the bait was now removed and a gap of 4 days left in order to minimize any prebaiting effect, since the purpose of the plain bait was solely to give some quantitative estimate of the population for comparison with figures after poisoning.

In fact poisoning was done in the same bait base (sugar-meal) so that it is rather doubtful whether the experiment gives a true test of direct poisoning. The poison used was zinc phosphide at a concentration of 5% and it was laid at forty points in the main room and at fifteen points in each of the two adjacent rooms. This was left down for 3 days, but no measure of the amount taken was attempted. Postbait of oatmeal was laid immediately in all three rooms. This decision again was perhaps unfortunate, since oatmeal had shown itself one of the least-liked baits in the choice test, but as soon as small amounts began to disappear in the two side rooms (7 days after the end of poisoning) plaster of Paris patches were put down in all the rooms. The main purpose of this was to check the direction and speed of reinvasion (see Ch. 2), but it also proved that the poisoning had been successful, and that the absence of feeding was not merely due to dislike of the bait.

This experiment has many disadvantages, but these are common to tests which simulate direct poisoning, while at the same time using plain bait for a census. There is no doubt, however, that a complete kill had been obtained, and that in such an environment where food is scarce and unpalatable, prebaiting would be a waste of time.

Finally we must mention experiments in poisoning corn-ricks. Full details are given of all the tests made in Chapter 13, but the main results were that direct poisoning would kill from 50 to over 90% of the population provided that the bait used was moist sausage-rusk and the poison zinc phosphide. Results in some cases were quite spectacular, and prebaiting,

besides being laborious and uneconomic (on account of the number of baits that have to be placed) would probably cause little increase in efficiency.

These results therefore support our previous assertion about the kinds of premises where prebaiting is unnecessary. Such infestations should be carefully distinguished during inspection or trace testing, since, if we can omit prebaiting much material and labour are saved. Only two visits are necessary (apart from inspection), so that the labour bill will be reduced to at least half.

3. THE ACTUAL PRACTICE OF A POISON CAMPAIGN

The present section will follow through the main design of a campaign with special attention to prebaiting.

(*a*) *Equipment.* Baiting tins and so on have already been mentioned. So also has the necessity for a powerful torch. The type equipped with a battery to fit into the pocket and the lamp to fasten round the forehead with an elastic band is extremely useful where baiting has to be carried out in dim places, since the hands are left free but the beam can still be directed wherever it is wanted. Only after experience can we realize how easy it is to overlook and leave behind one or two poison baits, especially as the best places to lay these are always the darkest and most protected corners. For the poison bait it is almost essential to use small slips of cardboard about 2 in. square so that there is no danger of leaving traces of poison behind, and the job of clearing up can be done quickly and efficiently. Furthermore, if these slips are coloured brightly (yellow or light red show up well), the chances of overlooking one or two are much reduced. Where bait points are placed out of sight chalk is useful as a marker and a reminder, and if we need to be particularly careful, each bait point can be chalked with a number, so that it is well nigh impossible to overlook any. Even so, it is remarkable how long one can spend hunting for an elusive point.

(*b*) *Choice tests.* These need not be carried out on the whole population. Half a dozen points with about 30 g. of each bait to be tested are ample. It is as well to have rather larger quantities than are likely to be eaten. If one is preferred and finished, then mice may be forced back on the less popular foods and the result may not show the true degree of preference. If a moist bait is included in the choice, the amount of water in it must be disregarded for the purpose of comparison. It is as well not to run a choice test for more than 2 nights, and usually 1 night will show a decisive result. This avoids prolonging the prebaiting (with the danger that the mice will go back to their original food) and also saves labour and expense.

(*c*) *Density of baits and measurement of prebait take.* The number of baits to be put down must of course depend on the judgement of the operator and on the results of his inspection, but he should always err on the generous side. On the average one bait to every 2 sq. ft. is not too much for a bad infestation, though this average figure does not take account of the fact that

the bait will be unevenly distributed. Experiment No. 4 (see p. 165) gives more details about this subject.

The prebait should preferably be measured every day so that the bait eaten can be replaced and the movements of the mice checked with greater accuracy than if they have to forage about for more baits. Sometimes, when the main focuses of infestation have already been narrowed down, visits need only be paid every other day if the bait is a kind which does not deteriorate and plenty is left. Even so, it is difficult to achieve for certain the best effects of prebaiting.

An experiment in the Oxford market (Table 53) shows the danger of this. Even if we allow for the gradual rise throughout prebaiting, we must still conclude that 2-day takes are considerably less than twice single-day takes. This is presumably because if the mice have to search around they must increasingly come in contact with their old food supplies, and they will therefore be diverted back to them. The best way of prebaiting in face of the diffused feeding behaviour of mice is to present them, whichever way they turn, with small piles of bait, and to achieve this the baits must be renewed daily.

TABLE 53. *Effect of leaving prebait down for 2 days on daily average take*

Day:	*2+3*	*3+4*	*5*	*6+7*	*8*	*9*	*10*	*11*
Baits laid (1·5 g. each). . .	262	267	254	242	267	318	319	323
Baits taken . .	147	193	161	187	164	200	243	269
Daily take . .	(av.) 73	(av.) 96	161	(av.) 93	164	200	243	269

There is a further danger in leaving the prebait down for 2 days. If the bait used is a moist one (e.g. sausage-rusk mash), it will harden sufficiently during this time to become less palatable. So a drop in the average daily take may be expected from this cause as well as from increased foraging.

The daily consumption of prebait is, of course, a measure of the population treated, but it is very difficult to know what proportion of their daily food is bait. Mice are rarely caught with prebait only in the stomach (see Ch. 8), even though the amount taken has appeared to be most satisfactory. Probably, therefore, all we can hope from this measure is a minimum figure for the population, viz. supposing that only prebait is being eaten, then the daily take divided by the mean daily requirement of a single mouse (see Ch. 3) will give the smallest possible number of mice that can account for this amount. Even such a figure is sometimes useful.

In localities where there is little food, this figure may be nearer the true population. At a draper's shop in Oxford, where we must suppose the mice had been living mainly on scraps, we baited with 1·0-g. piles of rolled oats and recorded a mean daily consumption of some 40 g. When traps were put down fifteen mice were caught and these seem to have been the whole of the population since no more food was eaten for 7 days afterwards. At a mean

daily consumption of 3·6 g. these mice would have been eating a total of 54 g., which means that only 14 g. or about $\frac{1}{2}$ oz. per day came from sources other than the prebait.

The length of time for which prebaiting should be continued is another matter about which it is difficult to be dogmatic. In the case of 'easy' infestations, where food is scarce or mice can be intercepted, there is less danger of the mice losing interest in the bait and it is probably safe to prebait for a week. In practice this limit is unlikely to be exceeded for economic reasons, and, in fact, many people will prefer to prebait for 2–3 days only, even if this means slightly less good results. Table 54 shows from tests made or overseen by the Bureau how often in 'easy' environments the prebait taken dropped again after rising to a peak.

TABLE 54. *Poison tests by the Bureau showing proportion in which prebaiting was continued too long*

	Peak amount of prebait taken in one day	*Peak occurred on day*	*Definite drop on day*	*Amount of drop (g.)*
Dry cleaner's cellar .	52 g.	12	13	13
Draper's shop .	53 g.	11	12	30
Electrical equipment factory . .	183 g.	6 (incl. 4 days' choice test)	7	41
Store shed with canned goods .	35 g.	4–5	6	5
Basement of Pathology Dept. . .	15 g.	7	8	12
Boiler room . .	60 g.	5	No drop occurred before poisoning done next day	
Store shed with canned goods .	90 g.	7	,,	
Basement of Pharmacology Dept. .	128 g.	11	,,	

It is even less simple to fix the minimum amount of time for which prebaiting should be continued, since this depends on the skill of the operator and the amount of information that he requires. In most of the Bureau tests prebaiting was continued until the distribution of the mice was quite clear and the greatest possible effect of prebaiting had been obtained. This usually took about a week. From the practical point of view, however, if the bait is well spread and distributed on the first day and then concentrated in the main sites of infestation on the next day, it should be quite profitable to poison on the third day if the infestation reveals itself as an 'easy' or vulnerable one.

(*d*) *The placing of the poison bait*. Little need be said about this, since the prebaiting will already have shown where to put the poison. In most of the Bureau's tests quite as much poison bait as prebait has been put down,

although only a small portion of it is likely to be taken. Probably some saving could be made by using smaller quantities: if the prebaiting has been done in 1-g. piles, the poison bait need only consist of ½-g. piles. We have already drawn attention to the care that is needed to make sure no poison is overlooked when clearing up. This is not only a matter of safety because, if traces of poison bait are left, reinvading mice may take sublethal doses and thus be resistant to a further poisoning.

(*e*) *The length of time to leave down the poison.* This will depend upon whether prebaiting has been used. If it has and the mice have all been successfully reached, then a single night is enough to leave down the poison. With direct baiting, however, it is as well to leave the poison down for at least 2 nights in case mice which have not yet found the bait take it on the second night. This is often seen in corn-ricks, where mice may continue to take the bait for 2–3 days after it has been laid. This is presumably because the mice do not always come to the outsides of the rick every day, so that there is a continuing trickle of inexperienced mice finding the bait. The information on this point summarized in Table 55 is rather incomplete. The only instance in which prebaiting was used and the poison was left down for more than 1 day and measured each day was an early test in which the prebaiting was not very efficient, so that the small poison take on the second day may have been due to this cause.

TABLE 55. *Take of poison bait when left down for more than 1 day*

Locality	*Method used*	*Measure of poison action*	*Day*			
			1	*2*	*3*	*4*
Grocer's store .	Prebaiting with RO: poisoning with 15% arsenic in same	Take	0·7 g.	0·1 g.	0	..
House . .	Direct poisoning with 10% ZP in flour	,,	0·7 g.	0	0	0
Food store .	Direct poisoning with 10% ZP in moist rusk	Corpses picked up	5	..	..	1
Rick A . .	,,	,,	220	101	..	..
Rick B . .	,,	,,	15	8	..	..
Rick C . .	,,	,,	64	10	1	..

(*f*) *Poison bait take.* Some idea of the success of a campaign can usually be derived from the amount of poison bait eaten and for comparison between different localities this may be conveniently expressed as a percentage of the last day's take of prebait, or of the mean of the last three days. Some figures from free-feeding tests in Chapter 5, giving comparisons between different poisons may here be referred to. The proportions are much the same in field trials: with zinc phosphide a take of poison bait equal to 10% of the prebait peak is good and less than this may give quite satisfactory results.

With arsenious oxide the amount eaten varies greatly, and it is not so easy to form a judgement unless postbaiting or trace testing has been done for confirmation. A list of some of the more important of the Bureau's trials together with the amount of poison taken and the general result of each campaign is given in Table 56.

TABLE 56. *Poison take in various tests compared with results*

Locality	*Treatment*	*Poison-bait take % last prebait take*	*Result*	*Corpses picked up*
Museum cellar.	Toasted oats+2% A	23	Good	0
,,	Rolled oats+5% A	10	,,	0
,,	,, +10% A	7·5	,,	0
,,	National flour+2·5% ZP	7·1	,,	0
Grocer's store .	Rolled oats+15% A	6·7	Fair	0
Dry cleaners .	,, +15% A	6·5	Good	0
M.O.F. store .	,, +10% ZP	13·3	Fair	10
Municipal Restaurant .	Oiled r.o.+10% ZP	20·8	Good	0
Theatre dressing rooms .	,, +10% ZP	16	,,	0
Grocer's shop .	Rolled oats+5% ZP	20·9	Fair (but obscured by reinvasion)	11
,,	,, +5% ZP	7·3	Poor	2
Basement of Pharmacology Dept.	,, +5% ZP	8·2	Very good	26
,,	,, +10% A	16·6	,,	1
Electrical equipment factory .	Oiled r.o.+15% ZP	35·9	,,	19

A = arsenious oxide, ZP = zinc phosphide

The variation in these figures is probably due to incomplete prebaiting, especially in the very high takes recorded.

(*g*) *Number of corpses picked up.* As with rats, corpses are only consistently found after using zinc phosphide and red squill. The numbers picked up after various experiments are given in Table 56, and it is evident that even with zinc phosphide the variation is very great. This will depend partly on the actual density of the mice and partly on the density of the cover. In any case the number of corpses is of no particular value in assessing the success of the poisoning.

(*h*) *Assessment of success.* For practical purposes and to avoid further expenditure of time and materials subjective evidence may be used. The owners of the premises, if the infestation was bad, will be only too pleased to note decrease in or lack of damage, absence of noise, smell, and traces, and frequently the relief to the nerves of their staff. But in addition most operators will want to make at least one inspection of the premises after

poisoning and to apply some of the suggestions made in the first section of this chapter.

When there is time, it is better to have an objective measurement of the decrease in the mouse population, and of course during experimental work such a procedure is indispensable.

In 'easy' environments it often happens that the clearance approaches 100%, and where this is suspected from the amount of poison bait eaten it is sufficient to lay some plaster of Paris patches in the places that were most frequented by the mice. This will indicate overnight whether the mice have all been killed, but, as explained above, even a few survivors will obliterate the surface of the patches, so that the method is no good for giving a quantitative estimate of the number or proportion surviving.

In all the Bureau's experiments, whenever we have put down plain bait before poisoning, we have reverted to it immediately the poison bait has been taken up. Postbaiting like this gives a fairly precise relative figure for the decline in the population, but there are several points to watch if we use this method.

In the first place the same food should be used for postbait as for prebait. The reasons for this are fully explained in Chapter 9. The same food must reasonably be expected to give a more precise result by eliminating the unknown disturbance which a change in food would produce, and the mice do not associate the plain food with the poison which was offered in it.

Postbaiting, however, should be continued for several days, and, if possible, for a week, since after poisoning the surviving mice are apt to be shy of *any* plain bait for a short while, and so a superficial postbait may give the impression that the campaign has been more successful than is the case. On the other hand, there are difficulties about this because within a week more mice may invade the emptied premises and this will confuse the figure for postbait.

The only safe way is to continue postbaiting until the figures have risen to a fairly steady level, and if this does not occur within a week, then one must assume that reinvasion is obscuring the picture. Table 57 shows the course of postbaiting in various of the Bureau's tests.

In almost every instance there is some rise in the postbait which emphasizes the danger of using a figure immediately after poisoning. On the other hand, in 5–7 days the amount taken usually reaches a 'plateau', so that one can assume it to be a fair representation of the surviving number of mice. Of the two exceptions in Table 57 experiment No. 6 was definitely due to reinvasion, since the buildings cleared were surrounded by infestations equally or nearly as bad: the other (No. 10) may be due to the fact that arsenious oxide generally produces greater shyness of the postbait than other poisons. This may be rather an exaggerated case, since other experiments using arsenic show that the postbait will become steady within the 5–7 days mentioned. In any case it is necessary to be very careful when

using arsenic: the figures for the first few days' postbait in experiments 1, 9, and 10 show how deceptive this poison may be. If we had not continued measurements it would have been natural to assume that nearly all the mice had been exterminated.

TABLE 57. *Rise in postbait at various localities after poisoning*

Locality	*Prebait peak*	*Poison*	*Postbait. Day* 1	2	3	4	5	6	7	8	9	10
1. Grocer's store .	8·5 g.	A	0·4	0·4	3·4	3·4	3·8	3·8	3·7	3·7	3·7	..
2. Confectioner's shop	35 points	A	1·5	3·5	7·5	8·5	8·5	..	..	..	..	..
3. Oxford market, northern half	269 points	Sq	87	124	84	84	140	86	86	..	..	..
4. Oxford market, southern half	140 points	ZP	7	7	12	12	12	13	13	..	..	..
5. Pharmacology Dept.	128 g.	ZP	5	6	13	15	16	..	..	..	..	..
6. Grocer's store	145 g.	ZP	11	3	6	6	6	6	6	13	13	16·6
7. Food store, oat stack No. 2	61 points	ZP	30	21	16	29	29	..	..	37	46	36
8. Food store, oat stack No. 3	50 points	ZP	7	8	6	8	13	..	..	14	14	10
9. Food store, flour stack No. 7	29 points	A	0	1	..	..	24	33	33	37	34	..
10. Food store, flour stack No. 8	46 points	A	0	8	..	..	16	14	15	30	40	..

A = arsenious oxide, ZP = zinc phosphide, Sq = red squill

Some of the experiments (Nos. 3 and 7) show a virtual absence of shyness and mice began to feed again at the highest level. This may happen when the poison bait has been indifferently taken.

(*i*) *Second treatments.* We need say little about these except that the sequences of poisons recommended in Chapter 9 should be followed, and the bait need not be changed. The first treatment will have settled all the details of distributing the bait, and the only point left to decide is how long a period should separate the two treatments. This can be answered from Table 57 which shows that on the average we should not attempt a second treatment before 5–7 days have elapsed, and if arsenious oxide has been used possibly longer still, according to the progress of the postbaiting.

It is rarely necessary to carry out more than two poisonings to reduce a population in an 'easy' environment to negligible proportions. The problem of any further treatments will be dealt with in the next chapter.

The course of a poisoning campaign has now been followed through in its entirety and the main objects and principles should be clear. As an illustration, however, of the way in which prebaiting properly applied can unmask an apparently difficult infestation and reveal it as an easy one, the following experiment by the Bureau is quoted.

Confectioner's shop, Oxford. This was a small house in a row on the outskirts of Oxford and it was used as a shop and store for grocery and confectionery. The ground floor consisted first of a large L-shaped room, one end of which took up the whole front of the house. In this room current stores were kept stacked on the floor and on shelves for sale, and a certain amount of unavoidable debris and crumbs were left about. Fitting into the angle of the L was a passage, again shelved to hold current stores, leading into the kitchen at the back of the house. In this kitchen and in a cupboard under the stairs opening on to the connecting passage were kept stores of a more permanent nature, mostly in tins, packets, and jars. The kitchen also necessarily contained a fair amount of opened food, since it was here that the meals for the café were prepared. Out in the garden was a wooden shed in which the larger bulk stores (sacks, tins, and packing cases) were kept.

The first and only other floor consisted entirely of living rooms: a large one in the front over the shop and two other smaller ones, one over the back part of the shop, the other over the kitchen. The dimensions of all these rooms are given in the accompanying plans, which illustrate the course of the campaign (Fig. 16).

The occupant of the premises gave the following history: they had been badly kept until they came into her possession about 6 months previously and mice had been permanent residents (this was obvious from the old holes in skirtings and walls); at the change of tenancy the place had been completely cleared up, but since then the mice had gradually re-established themselves and were now visiting all rooms in the house. Several weeks previously Rodine had been put down and the first treatment made some improvement. Subsequent baits had, however, been left untouched, or in some cases the bread had been eaten and the layer of Rodine smeared on to it had been left. At the moment both the houses adjoining were known to be badly infested with mice (the one to the east was also a grocer's shop).

The main damage was to cereals stocked in bags or cardboard cartons, but margarine had also been eaten, and in one of the rooms on the first floor the drawer of a desk had been entered and a pair of silk stockings shredded up. An inspection of the premises showed mouse traces in all the rooms except the kitchen and the store cupboard under the stairs, and they were particularly concentrated in the shop. Except in the outdoor shed and the cupboard under the stairs (into which the mice fortunately did not find their way throughout the campaign) the goods were stacked so as to give little real cover and it was clear that the mice moved about the house between floors and behind skirtings and walls. Accordingly $\frac{1}{2}$-g. bait points of rolled oats were distributed fairly evenly all over the premises during the morning of one day and examined 24 hours later. The distribution of takes is shown on the plan, and illustrates the way in which the mice were covering the whole of the premises. In two places, however, the corner of the shop and the first floor back, all the baits put down had been eaten, and so

the numbers of baits at these places were increased. This process was intensified gradually during 6 days of prebaiting, and with minor variations the take was narrowed down to these two places and the outdoor shed, which

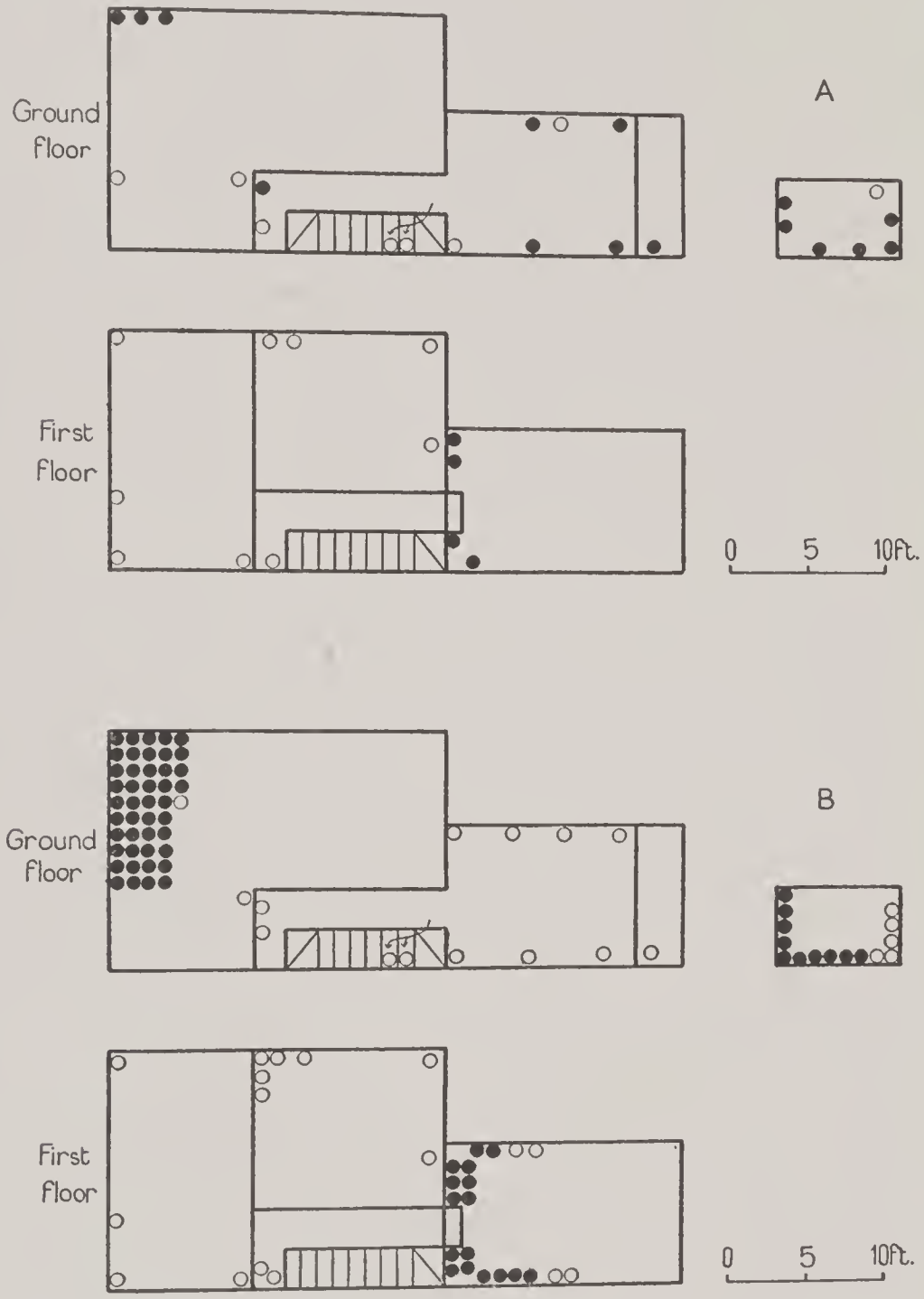


FIG. 16. Distribution of baits eaten in confectioner's premises after the first (*A*) and last (*B*) days of pre-baiting. Black circles show bait piles eaten, open circles bait piles uneaten.

clearly represented a separate infestation. The variations consisted of occasional takes in the other first floor rooms, but these were not constant and did not obscure the gradual emergence of the picture shown as a result of the last day's prebaiting (see plan), when 44/45 baits were taken in the shop,

16/20 in the first floor back, and 10/15 in the shed. After this day it was decided to poison since a surplus had been obtained at each of these points. This presumably meant that all the mice were now coming to the bait.

The situation shown by the plan illustrates well how an infestation that at first would be classified as difficult is revealed by prebaiting according to the method described in Chapter 9 as being a very simple one with the mice entering at three places and not living on the premises at all. The first floor back was the only dubious place, because it seemed possible at the time that these mice might be living in the walls of the house or between the floors and ranging out into this room as a separate unit from the ones in the shop. The poison used was 10% arsenious oxide in the same food used for prebaiting (rolled oats). It was thought advisable to use this poison, since many of the mice were obviously shy of Rodine phosphorus, and it was still uncertain then whether this would make them unwilling to take zinc phosphide. Some 74 points (45 g.) of this poison were put down, 38 in the shop, 10 in the first floor back room, and 15 in the shed. The rest were dotted about in single points in case the mice should behave unusually.

Investigation on the following day showed a very interesting result. The total amount of poison taken was 3·5 g. (= 7·8% of the prebait peak), and, apart from the outdoor shed, the whole of this was eaten in the shop corner. In this place the bait piles had been placed underneath the window counter round the margin of a brick rectangle about 1 ft. square. On this the bait piles had been eaten successively along one side and half-way down the next, when the take stopped abruptly, giving the impression that all the mice had emerged at this point, taken their first feed straight away and then retired to die. Thus they never even got out into the shop proper, much less as far as the first floor back, which was clearly proved now to have belonged to the shop infestation. After this prebait was put down (rolled oats again) and in 5 days the take recovered to a level of about 19 points per day. If this is compared with the peak of the prebait (70 points), this represents a reduction (i.e. kill) of about 73%, which is fairly good for house mice, especially when arsenic is used. At the end of the 6 days' postbait 5% zinc phosphide in rolled oats was put down and was taken only in the shop and in the shed. For 9 days after this no postbait take was recorded at all in the house and only an occasional take in the shed (the total clearance was very near to 100%), which then dropped out of consideration by being mouse-proofed. This phase of the clearance was now considered as ended.

4. REINFESTATION AND MAINTENANCE

With mice the speed of reinfestation may be very rapid (this has already been discussed in Ch. 2 and examples cited). From a practical point of view reinfestation calls for no particular comment because most of the mice will be new ones and will not be shy of the poison that has just been used to clear the premises. They can, therefore, be dealt with without a change of poison,

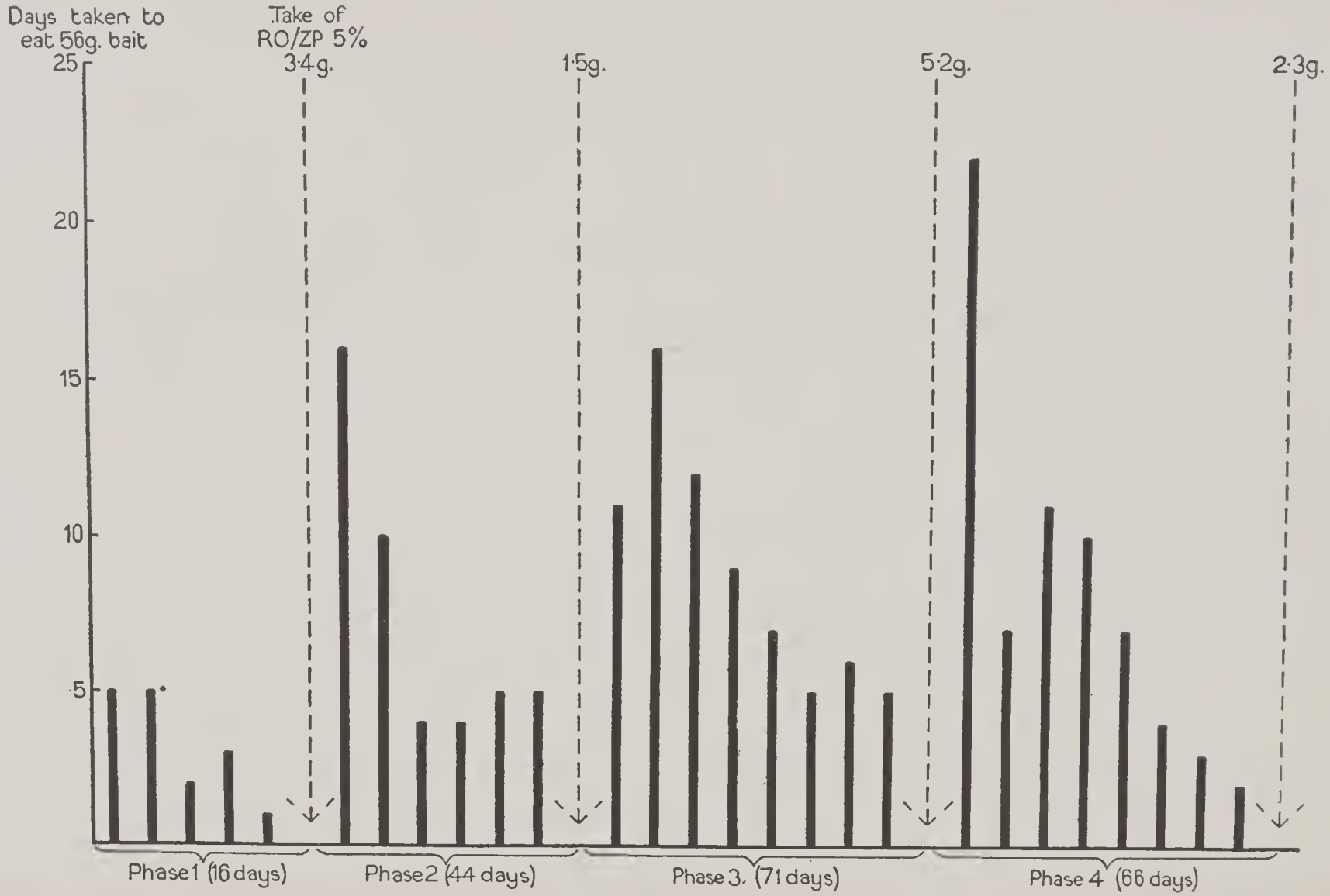


FIG. 17. Successive treatments with same poison to keep down re-infestation.

The best way in which to avoid reinfestation is by the simultaneous clearance of large blocks of premises, and the only method of doing this is by a simplified poisoning technique (say 2 days' prebaiting and the third poisoning) which allows so much more ground to be covered than trapping or other devices. The account of a block clearance project carried out by the Bureau is described in the following chapter.

At the confectioner's shop described above experiments were continued to discover a simple method of maintenance which would keep the premises reasonably free of mice and yet be simple and cheap to operate.

In this instance the circumstances were peculiarly favourable, since the mice were known to be entering the house at one point only and they could be intercepted even before they emerged into the shop. So a bait tray was placed underneath the window counter just where the mice came into the house (blocking the actual hole would have needed a major operation including taking up floor boards) and 2 oz. (*c.* 56 g.) of bait (rolled oats) were put in the tray. The owner was asked to note the time this took to disappear and then to rebait the tray with a further 2 oz.: when this time had declined to less than a week the Bureau was to be informed and more poison bait put down. The course of this experiment is shown in Fig. 17, and we can see from this that the premises were kept clear of mice for nearly 200 days with four poisonings. Each time rolled oats with 5% zinc phosphide was used, and the amounts taken show that mainly fresh mice were concerned. The rate of reinvasion varied slightly; it was fairly quick after the first poisoning (this being the follow-up treatment during the main poisoning campaign) and gradually became slower and slower. During the last two poisonings it was not worth while for about 2 months to put poison down. In addition the rate of reinfestation between each poisoning varied; during the first and second phases the mice came in more quickly at the beginning and then (in the second phase at any rate) slowed down. In phases 3 and 4 the rate apart from minor irregularities was fairly constant.

No doubt during this period some of the mice moved about the house itself, but practically no damage was reported and few signs could be found, so for the most part the bait tray engrossed the attention of the mice. This seems rather remarkable, but it again illustrates the success that will attend the careful siting of bait for interception.

Such a method for keeping mice out of cleared premises is not generally applicable, but its great advantage is that reasonably intelligent owners can do the job for themselves and save others the trouble of periodic visits.

II

POISON CAMPAIGNS IN DIFFICULT ENVIRONMENTS

1. WHAT IS A DIFFICULT ENVIRONMENT?

OFTEN it is very hard to judge what will be a difficult infestation to poison successfully. Of some there is no doubt, and these include all places where food and cover coincide and are extensive, such as corn-ricks and food stores. These, however, will be dealt with in Chapter 13, where more radical measures are proposed for killing the mice. This chapter concerns the large proportion of urban infestations in which for some reason poor results are obtained by poisoning.

In Chapter 6 the feeding habits of the house mouse were analysed and we showed that mice may approach and feed from a large number of food sources during one night, and that they feed by making many separate visits and taking tiny quantities each time. Furthermore, each night the more concentrated period of feeding is preceded by more discursive and interrupted visits, during which new sources are encountered more frequently than later in the night. This means that baits may be only sampled in very small amounts and, wherever there is plenty of alternative and accustomed food, baits will only be secondary (cf. stomach analyses of poisoned and trapped mice in Ch. 8). Thus difficult environments will have the following main causes, which may be encountered singly, or more frequently in combination.

(1) Localities in which there is plenty of food and cover all mixed up together. These are typified by the storerooms of shops, especially grocers' and confectioners', since here there is not only plenty of the preferred cereal foods, kept either openly or in vulnerable sacks and cartons, but jars and packing cases and sacks are piled together affording cover and nesting places as well as food. From neither can the mice be excluded without radically rearranging the goods and providing mouse-proof containers. This is usually far too expensive to be contemplated and would often mean less space for storing goods. The conditions have been typically described in Elton's notes, which are quoted in Chapter 3.

Under such conditions there is little chance of placing baits so as to intercept many mice on their journeys between cover and food, and certainly none at all of intercepting them *en masse*, as may be done in many easy environments.

An early experiment in a M.O.F. buffer depot, referred to previously on pp. 25–26 illustrates this with exceptional clearness. As mentioned, one room contained a small stack of about eighty oat sacks in which a certain

number of mice lived; the major part of the damage, however, was due to mice that visited the stack from the adjoining room, which was empty. We prebaited with dry rolled oats of which much was eaten on the route of the visitors, but very little from points placed around and on the stack itself. When we poisoned with rolled oats and 10% zinc phosphide the large quantity of 8 g. was taken on the runways which means that at least 20–30 mice, and probably many more, had eaten from here. The poison points round the stack were disturbed by workmen, so we could not measure the amount taken; from appearances it was very small. However, when the stack was broken down immediately after poisoning, only ten corpses were found in contrast to thirty-two live mice, which means that only about one-quarter of them were killed. The difference in the success in the stack and on the route of the visitors to it must have lain entirely in the disposition of the cover in relation to the food supply, and the stack mice would have been in a very similar situation to ones living among packing cases and goods in grocers' stores.

Other experiments, including a whole series in one particular shop and store in the middle of Oxford, gave much the same kind of result, indicating that throughout the baits that were put down were treated as secondary food only by the mice. During one phase of the experiments Elton used $\frac{1}{2}$-g. piles of plain bait put down for one night only at intervals as an index to the results of trapping and poisoning tests. In one room he trapped twenty-five mice and only reduced the bait index by a half (35/55 taken on day 21, trapping on days 21, 22, and 23 and 16/38 baits taken on day 28), so, if these twenty-five mice were only responsible for taking nineteen piles of bait (= about 9·5 g.) they must have been feeding for the most part on other foods. Later, during the experiment, he trapped eight mice without any detectable fall in the open bait index.

(2) We are bound to run into considerable difficulty in baiting at localities which include only part of the ranges of mice. Such conditions often arise when a single house in a row, or even a part of a single house, needs to be cleared. If the mice are taking refuge in walls and between ceilings, then it is quite possible that their wanderings, even if not extended by hunger, will embrace parts of more than one house, and it will be difficult to concentrate their attention upon bait which is only placed in one part.

The difficulties are made greater by a sort of internal oscillation set up within premises shared by different owners: when one section becomes careless about covering up food and leaving crumbs, the mice will be attracted there up to a point when their presence and numbers are so objectionable that action has to be taken. Their food supply is then cut off or reduced and they must move elsewhere within the buildings to another section which has in the meantime become careless. So with this shunting process perpetually going on we can never attract the mice consistently with bait.

Some experiments were done in an old house (*c.* 150 years) in Oxford, one of a terrace, and it was found extremely difficult to make any sense out of the results because of the sporadic nature of the visits. The ground floor of the house consisted of three rooms, and plaster of Paris patches revealed activity in only one of them. Poison was placed here without any prebaiting and a fair amount taken (0·7 g.) the first night. After this for 3 days there were visits to this room, as shown by footprints, but no more poison was eaten: neither of the other two rooms had any traces of mice. The next day activity had ceased, but had broken out in one of the other rooms. On the next day abundant activity was found in every room, a complete helping of custard had been eaten and a hole bitten in an expensive carpet. For 3 nights following this episode no activity at all was shown on the plaster of Paris, then 4 days of moderate activity (but no plain bait taken) were followed by another bout of quiescence.

This unpredictable course of events shows how difficult prebaiting and poisoning would be unless the campaign could be carried out on the whole block of houses at once.

(3) Another difficulty in urban environments, though not so troublesome as the two previously mentioned, is that in a heterogeneous habitat such as a block of houses or shops in which food supply and other conditions vary sharply even from room to room, bait preferences of the mice may differ over remarkably short distances. This is not a common phenomenon, but occurred several times in our experience and in one instance made the success of our poisoning tests very patchy.

(4) A consequence of these facts is that, even if an area is successfully cleared, it at once constitutes an attractive environment into which surrounding mice can expand. The speed with which mice will reinfest premises that have been treated has already been mentioned and illustrations given in Chapter 2, and the planning of a campaign must take account of this factor, otherwise we may spend much time uselessly moving round many topographically related places with the mice following behind us.

Needless to say any combination or all together of these four factors, which make house mice difficult to poison, may be encountered, making the matter even more complex. The worst instances are probably those in which (1) and (2) are combined, and the aggravation is greatest in very old buildings.

During the war an infestation was reported in some college buildings in Oxford, which were occupied by the military. We inspected them and found that the mice were particularly bad in a block of great age used as kitchen premises. The walls were extremely thick, crannied in many places, and had ill-fitting cupboards and recesses; floors were uneven and similarly ill-fitting; and the general lay-out of the buildings was complicated by sudden changes in floor level, winding corridors, and extensive cellars beneath. Food stores were kept in a number of rooms besides the kitchen

and large quantities were spilled about both in places where they could not be swept up and in places where they could have been swept up but were not.

Here we tried to carry out a census experiment by baiting first with 1-g. piles of rolled oats, waiting until a fairly steady amount was taken every day, then trapping with break-back traps and observing the effect of this on the amount of plain bait taken. Table 58 gives the results of this attempt.

TABLE 58. *Plain bait take before and after trapping*

Day:	*1*	*2*	*3*	*4 and 5*	*6 and 7*	*8 and 9*	*10*	*11*	*12*	*13*	*14*
No. of points laid	70	74	71	80	102	20 mice	75	98	90	73	73
No. taken . .	33	40	34	55*	62*	trapped	35	35	38	39	37

* = 2-day takes.

The figures show that the mice were not even beginning to be properly prebaited. The population must have been very large for the removal of twenty to have no noticeable effect upon the amount of bait taken, and clearly the latter was only a very subsidiary supply of food for them.

In this instance the large, varied, and dispersed stores of food available to the mice could not be cut off from them, even in part, because of the ramshackle nature of all doors and fittings. Cover was extensive and impenetrable, both in the recesses of the walls and in the jumble of stores, cooking equipment and utensils, so that it was difficult to make sure that the baiting covered all the ground. Probably large numbers of mice hardly touched the bait piles at all.

Such circumstances are the worst for keeping the attention of the mice away from baits or ensuring that they shall give them only a cursory glance. However, there are always gradations, and really bad places, such as the above are rare; in the intermediate kind of place there is always a good chance of obtaining reasonable results by certain modifications of technique. Time and trouble are needed, but it is at least fair to say that equal results cannot be obtained by any other methods.

2. MODIFICATION OF METHODS IN DIFFICULT ENVIRONMENTS

The greatest care should be taken over the inspection and special attention given to exploring the *whole* building and as much of adjacent ones as is practicable. This should be done, even if it means that extra time is taken in tracing other owners and getting them to agree to a comprehensive campaign. Apart from this general rule the following specific points should be observed throughout all campaigns of this kind.

(1) A preliminary bait-choice test should always be done. This need only take an extra day and, though the result often confirms previous suspicions,

there are occasions when a surprise is met. The sites for this test should be chosen according to the main food types available. Obviously if of two adjacent premises to be treated one is a grocer's and the other a butcher's, the bait preference should be tested in each place. The description of experiments in the Oxford market (see later) shows how bait choice may vary within quite small distances.

(2) In these circumstances particularly one must be prepared for long campaigns involving several treatments, so that we must think ahead in choosing the best sequence of poisons. It is best to use the same bait throughout once we have discovered the mice's preference from the choice test. This will carry us through the usual first treatment and follow-up, which are necessary in all but very easy environments. It is of no great moment whether zinc phosphide or arsenious oxide is used first. We should probably use the more toxic and successful one first to get as complete a clearance as possible at the first onslaught. On the other hand, if there are great numbers of mice whose bodies will smell objectionably, it is better to do the initial poisoning with arsenious oxide and follow with zinc phosphide when the numbers have been reduced.

When a third or even a fourth treatment is necessary there are one or two alternatives. The bait may be changed to sausage-rusk mash or rolled oats mash and red squill extract used for poisoning. The danger here is that the moist bait may not be so palatable as the dry, at any rate in some parts of the area to be treated. For this reason it is useful to have included one moist bait in the preliminary choice test, so that we may know beforehand how acceptable it is. Another alternative is to use a new poison entirely such as α-naphthylthiourea; more detailed results with this substance are given in Vol. 1, Chapter 4. Finally, it is worth trying the inclusion of masking substances (see Ch. 7) in the bait, and repeating the first two poisons.

We do not know exactly how long a poison-shy population will resent the repetition of straightforward zinc phosphide and arsenic baits, but after 6 weeks or 2 months, especially in localities where reinvasion is taking place, sufficient inexperienced mice will have come into the population to make such a repetition worth while.

A long and involved experiment, which was carried out at a shop in the Oxford market, illustrates the kind of bait sequences that can be used, though it also shows some of the errors to avoid. The shop concerned was a grocer's and greengrocer's, consisting of one fairly large room in which goods were stored and displayed, both on the floor and on shelves and counters; in the roof above this an area about a quarter the size of the whole shop had been floored for use as a store and was reached by a ladder. Behind the shop was one medium-sized office and a smaller one above it. These premises backed on to a butcher's, both forming the end of one block of buildings, throughout which there was unlimited communication. In the early part of the first phase of the campaign and during the whole of the

second phase these premises were treated on their own and reinvasion was a factor of great importance. Table 59 gives in a summarized form the course of the campaign. For each poisoning the peak of the prebait and of the postbait is given (the latter of course being the prebait for the next poisoning), and the length of time intervening between each trial is shown by the day numbers given at the head of each column. Every time the premises were treated on their own the postbait figure is greatly complicated by reinvasion, and it is probable that far more mice were killed than the figures suggest.

The trial with red squill extract was preceded by prebaiting with sausage-rusk mash, but, since this was not well taken, rolled oats mash was used instead. The actual figures for this have been omitted because the subject is treated in more detail at the end of this chapter, where the poison trials for the market as a whole are described.

TABLE 59. *Sequence of poisonings at a grocer's shop in the Oxford market between 10 August 1943 and 10 June 1944*

FIRST PHASE

Day:	3	6	8		9	11
Bait:	*Rolled oats*	*1st poisoning: moist sausage-rusk + 10% ZP*	*Rolled oats*	*Result of first trial*	*Flour*	*2nd poisoning: flour + 2% Antu*
Points (*c.* 2 g.) laid	23	Very poor take	25	Nil	35	Very big take, 24 g. eaten and 10 corpses picked up
Points taken	17		22		22	

Day:	22		25	33		38
Bait:	*Flour + 10% sugar*	*Result of 2nd trial*	*3rd poisoning: sugar-meal + 2% Antu*	*Rolled oats*	*Result of 3rd trial*	*Rolled oats mash*
Points (*c.* 2 g.) laid	20	Fair reduction, quickly obscured by re-invasion	2 g. eaten No corpses	25	Nil	24
Points taken	18½			19½		20

Day:	39	44		50	51	
Bait:	*4th poisoning: rolled oats mash + 1% red squill extract*	*Rolled oats*	*Result of 4th trial*	*5th poisoning rolled oats + 10% ZP*	*Rolled oats*	*Result of 5th trial*
Points (*c.* 2 g.) laid	Taken fairly well	25	Good reduction	Very small take	27	Nil
Points taken		9			7	

TABLE 59 (*cont.*)

SECOND PHASE (*after 6 months' interval*)

Day:	*1–9*	*13*	*17*	*31*		*36*	*45*
Bait:	*Choice test*	*Rolled oats*	*1st poisoning: rolled oats + 5% ZP*	*Rolled oats*	*Result of 1st trial*	*2nd poisoning: rolled oats + 10% As*	*Rolled oats*
Amount laid (g.)	RO plain and oiled	200	..	50*	Big reduction	..	100
Take (g.)	Former preferred	145	21 g. 10 corpses	14*		9 g.	56

Day:		*48*	*50*	
Bait	*Result of 2nd trial*	*3rd poisoning: rolled oats + 5% ZP*	*Rolled oats*	*Result of 3rd trial*
Amount laid (g.)	Little reduction, but result of trials 1 and 2 obscured by reinvasion	..	100	Hardly any reduction
Take (g.)		4·5 g. 2 corpses	40	

* = Mean of 2 days.

In the first phase of this experiment the initial poisoning was very badly chosen, and the opportunity was missed of making a clean start and getting the bulk of the resident population straight away. In the first place no choice test was done and in the second place the bait was changed for poisoning. This latter was due to an attempt to follow the principle used in rat campaigns of keeping one acceptable food for census baiting, and using another for prebaiting (if any) and poisoning. Both these were bad mistakes, as can readily be seen by comparing the result of the initial poisoning in the second phase, in which a very large population was reduced by nearly 90%.

The two trials with α-naphthylthiourea which followed this first failure were quite satisfactory as far as prebaiting technique was concerned; a large poison take was secured, and the number of corpses found must have represented a good kill. In the table the peak postbait only is given, but in fact the take returned to this region in a very short time (about 4 days), so that, unless reinvasion was very prompt, a number of mice must have recovered from sublethal doses of the poison. The very much reduced take during the third poisoning, which was practically a repeat of 2% α-naphthylthiourea except that 10% sugar had been added to the bait, shows that poison-shyness must have been present.

During the fourth and fifth poisonings of the first phase all the neighbouring premises were being treated at the same time and the reduction of

the population to less than a half must mainly be attributed to the consequent damping down of reinvasion. The repetition of a zinc phosphide bait was hardly any advantage at all, and this trial should probably have been done with arsenic. Even 6 weeks after the initial trial using this poison there must have been a considerable number of mice which were shy of it. However, in this instance the sequence fell into line with the larger campaign being conducted over the whole market.

After the lapse of 6 months a very large population had built up and this was treated in a more orthodox manner, observing the lessons that the first phase had taught. The choice test revealed a decided preference for plain rolled oats compared with the same bait mixed with oil and this was therefore used throughout. The total take was also measured more precisely by the method mentioned on page 153. The prebait peak was very large for mice; so was the amount of poison bait eaten (14·5% of the prebait peak), and this must have been still further reinforced by the successful take of arsenious oxide 19 days afterwards. Unfortunately, reinvasion again obscured the picture, though even so the population was reduced to under 40% of its previous level. The third poisoning with zinc phosphide killed a number of mice (the take represented nearly 9% of the prebait peak), though the result again may have been obscured by reinvasion. Even so, it is probable that only fresh mice took this bait, and it would have been wiser to use a third poison or to mix a masking substance with the bait.

From this rather tangled story we learn the following facts for guiding us in the treatment of difficult infestations.

(1) Block treatment is always more satisfactory than separate treatments of small units.
(2) Choice tests are indispensable.
(3) Continuous treatments may be arranged at about fortnightly or 3-weekly intervals to deal with the influx of newcomers, though for the length of three or four treatments the same poison should not be used again.
(4) After a continuous treatment of this kind during which all the usual poisons in their due sequence have been used, it is best to leave a considerable interval before starting again, though not necessarily as much as in the above experiment (6 months).
(5) This ensures a good kill at the beginning of each series of treatments, so that, even if residues have to be left behind, the damage is greatly reduced.

3. BLOCK TREATMENTS

During the treatment of the Oxford market described below an attempt was made to show that such a procedure was in the long run far more economic than a large number of small campaigns owing to the way in which reinvasion was checked; and also that an area of this size (the main part

treated first consisted of twenty shops, usually with 2–3 rooms each) could be dealt with quite quickly by two persons. During the experiment most of our time was taken up in making the necessary measurements of prebait and postbait take and so on; even so, the whole business did not take more than 1 hour per day (i.e. 2 man-hours).

The work was carried out by Miss Laurie and Southern with assistance from Rzóska. Poisoning trials were started at locality 10 on 11 August 1943, but it was not until 8 September that work began in the market as a whole, continuing until 10 November 1943. In August of that year D. H. Chitty had obtained an almost complete clearance of rats, but most shops still complained of the damage caused by house mice to their goods and thought that mice had increased since the decrease of rats. Throughout this work most shopkeepers appreciated the Bureau's efforts (only one refused to participate and twenty-one were not sufficiently badly infested to bother about) and left the bait points undisturbed. Nevertheless, it was inevitable, especially in grocers' and greengrocers' shops with their continual turnover of goods, that points, however carefully placed out of the way of disturbance, were obliterated or became inaccessible, thus confusing the results. The area covered by the infestation was too great to be dealt with as a whole, so north and south halves were treated consecutively.

North half. This was done first between 7 September and 4 October and involved twenty infested premises. The plain bait (2·5 g. rolled oats, 3 g. sausage-rusk mash or rolled oats mash) was put down in the morning between 9.30 and 11 when few customers had arrived, but, when possible, poison bait was laid about closing time (16.00 hrs.) on Saturday afternoon in order that it might remain undisturbed over the week-end, the remainder being cleaned up on Monday morning when the postbait was put down. Visits were paid once in 2 days and often daily in the first half of the treatment.

Three baits were used: plain rolled oats, rolled oats mash (1 part to 0·25 parts of water) with 10% sugar, and sausage-rusk mash (1 part to 1 part of water) with 10% sugar.

Dry rolled oats were always well accepted. However, in order to use red squill extract as a poison a wet base such as sausage-rusk mash had to be used, to which 10% sugar was added to mask the bitterness of the squill. It was also hoped to use the dry bait as a census to avoid confusion of the postbait figures by possible shyness of the bait.

Table 60 gives the whole course of events in the north half of the market. Figures in ordinary type represent the number of baits put down and those in italics the number eaten. The results are complicated by some of the totals being for 1 day and some for 2 days, so that they are not quite equivalent and cannot be adjusted.

The difficulty of changing to sausage-rusk mash for using squill extract was that in many places there was a drop in the amount eaten. Rolled oats

TABLE 60. *Oxford market, north half*

Bait	*Rolled oats*						*s.r.m.+10% sugar*		*s.r.m. r.o.m.*				*+1% squill*	*Rolled oats*								*+10% ZP*	*Rolled oats*	
Sept.:	*6*	*8*	*10*	*11*	*13*	*14*	*15*	*16*	*17*	*18*	*20*	*21*	*22*	*24*	*25*	*27*	*30*	*Oct. 1*	*4*
Shop No.																			
1	10 5	10 8	10 8	10 10	10 8	10 6	8 1 3 2	8 4 3 2	.. ..	.. ..	.. ..	10 10	10 8	10 4	.. ..	.. ..	10 —	10 2
2	14 3	12 8	12 4	12 8	11 5	11 6	6 4 3 3	6 4 4 2	7 6 3 3	26 — 5 —	12 4	12 6	12 6	12 2	12 6	12 5	12 —	12 0
3	7 1	6 ±	6 1	.. ..	.. ..	6 4	6 6	6 5	6 6	14 —	6 0	6 2	6 3	6 1	6 5	6 6	9 —	9 0
4	9 0	9 1	9 1	5 2	4 2	4 2	3 3	3 3	3 3	7 —	5 0	5 0	5 0	5 0	5 0	.. ..	.. ..	.. ..
5	4 1	3 1	3 1	3 1	3 3	5 0	2 1	1 1 1 0	1 1	5 —	3 0	3 0	3 1	3 1	.. ..	3 1	8 —	6 1½
6	5 3	6 6	6 5	6 6	6 6	6 6	6 6	6 6	.. ..	.. ..	.. ..	6 6	6 6	6 4	6 6	6 6	6 —	6 0
7	13 12	18 ±	.. ..	22 14	28 17	28 18	17 13 7 7	12 6 12 12	0 0 25 20	0 — 42 —	22 3	12 6	16 7	16 4	16 6	16 3	11 —	16 4
8	14 9	14 12	14 4	.. ..	.. ..	16 10	11 10 5 5	11 9 5 5	11 8 5 5	30 — 17 —	14 1	14 4	20 8	20 11	20 14	21 9	9 —	21 3
9	.. ..	.. ..	.. ..	3 2	9 2	9 0	3 0	2 1	.. ..	2 —	3 1	3 1	3 3	3 3	3 3	3 3	3 —	3 1
10	.. ..	.. ..	.. ..	.. ..	23 5	23 15	15 8 7 4	8 2 13 13	0 0 24 20	0 — 50 —	25 10	25 8	25 11	25 9	25 14	25 14	27 —	25 6½
11	5 3	8 8	9 6	9 9	10 9	10 5	3 3 8 7	3 2 8 8	.. ..	20 — 11 —	9 5	9 8	9 9	9 8	9 9	9 8	9 —	9 8
12	6 5	6 6	6 6	6 6	6 6	10 10	10 10	15 10	.. ..	30 — 12 —	6 2	6 2	6 3	6 2	3 2	.. ..	5 —	3 2
13	25 23	25 22	29 22	29 25	29 20	29 25	38 33	29 24 9 6	.. ..	50 — 15 —	29 11	19 6 10 6	20 13 10 9	20 9 10 4	20 9 10 10	20 0 10 3	4 —	14 3
13a																	3 —	10 2
13b	7 0	7 1	7 1	7 3	9 1	9 0	4 2	3 2	.. ..	8 —	5 0	5 0	5 0	5 0	5 0	5 0	.. ..	.. ..
14	36 26	36 34	36 32	36 32	36 18	36 15	19 10 20 20	19 19 21 19	.. ..	45 — 25 —	36 21	19 16 19 9	19 19 19 18	19 16 19 10	19 16 19 13	19 13 19 14	13 —	14 11
14a																	15 —	16 7
14b	4 1	4 1	4 2	4 3	5 3	5 3	5 4	5 5	.. ..	7 —	4 3	4 1	4 4	4 3	4 3	4 4	4 —	4 1
15	18 12	18 15	18 13	18 13	18 9	18 12	18 14	18 17	.. ..	30 — 12 —	18 7	18 6	.. ..	18 14	18 16	18 15	15 —	8 1
15a	19 7	19 15	19 12	19 16	19 16	19 14	20 13	20 14	.. ..	25 — 10 —	19 4	19 5	19 13	20 9	20 12	20 20	22 —	20 4
16	21 4	21 14	21 6	.. ..	.. ..	20 15	20 17	20 19	.. ..	25 — 12 —	.. ..	21 2	21 4	21 1	21 1	21 5	6 —	13 3
17	6 2	6 6	6 4	6 6	6 6	6 4	8 6	8 8	.. ..	15 —	6 2	6 2	6 6	6 6	6 6	.. ..	5 —	6 4
18	9 8	9 8	9 8	9 8	9 8	9 6	9 6	9 8	.. ..	35 —	9 2	9 2	9 2	9 2	9 3	9 1	3 —	3 0
18a	23 16	23 20	23 18	23 15	17 11	23 15	26 17	26 23	.. ..		18 11	23 10	23 10	23 10	23 13	23 10	12 —	20 0
19	3 3	3 3	3 3	5 5	5 5	5 5	5 5	5 5	.. ..	12 —	3 0	3 3	3 3	3 3	3 2	3 3	3 —	3 3
20	4 3	4 4	4 4	4 3	4 4	4 4	4 4	4 4	.. ..	8 —	4 0	4 3	4 4	4 4	4 4	.. ..	1 —	3 2
Total	262 147	267 193	254 161	242 187	267 164	318 200	319 243	323 269	85 72	604 ..	256 87	290 124	283 169	302 140	286 173	272 143	215 —	254 69
Per day	.. 73	.. 96	.. 161	.. 93	.. 164	.. 200	.. 243	.. 269	.. ..	.. ..	.. 87	.. 124	.. 84	.. 140	.. 86	.. 47	.. —	.. 23

TABLE 61. *Oxford market, south half*

Bait:	*Rolled oats*												+5% ZP		*Gap*		*Rolled oats*					
Oct.:	*19–20*		*21*		*23*		*25*		*27*		*29*		*30*		*Nov. 1*		*3*		*5*		*8*		*10*
Shop No.														*Corpses*								
21	8	2	4	1	4	2	4	1	4	1	..	..	..		..	..	..	..	..	..	..	..
21*a*	2	0	2	0	..	..	..	..	..	..	..	..	..		..	..	..	..	..	..	..	..
21*b*	8	7	8	5	8	6	8	7	8	6	11	7	7		..	..	8	3	8	5	8	5
22	18	13	18	10	13	9	13	11	13	8	13	8	9		..	..	13	4	13	9	13	10
22*a*					8	6	8	6	10	8	15	10	9	1	..	..	13	5	13	9	11	6
23	44	33	39	27	..	..	39	27	39	34	41	33	30	2	..	..	32	1	32	6	32	1
24	45	21	37	16	34	13	34	11	30	20	30	8	15		..	..	26	1	26	4	26	2
25	9	5	10	6	10	4	9	7	10	9	10	5	5		..	..	5	0	5	0	5	0
26	11	5	5	2	9	2	9	4	9	2	10	5	7	2	..	..	10	1	9	4	9	2
26*a*	16	0	9	0	9	0	..	..	..	..	..	..	..		..	..	..	..	..	..	..	..
27	4	2	7	6	6	6	7	6	7	6	6	6	10		..	..	5	0	5	0	4	0
28	52	33	52	42	52	43	48	45	48	44	52	39	56	24	..	..	52	0	52	0	52	0
29	4	4	4	3	4	4	4	3	4	3	5	1	2		..	..	4	0	4	0	4	0
29*a*	5	3	5	3	5	5	6	4	6	3	6	3	3		..	..	4	0	4	0	4	0
30	9	2	9	9	9	8	9	8	9	9	9	8	9	1	..	..	8	0	6	0	8	0
31	16	3	10	3	15	5	15	9	15	5	15	4	9		..	..	9	0	7	0	7	0
31*a*	2	0	2	2	3	3	3	3	3	3	3	3	3		..	..	3	0	3	0	3	0
Total	253	133	221	135	189	116	216	152	215	161	226	140	174		..	..	192	15	187	37	186	26
Per day	..	66	..	67	..	63	..	76	..	80	..	140	..		..	..	..	7	..	12	..	13

TABLE 62. *Summary of results at Oxford market*

Nos. 1–20 were the north half, finished on 4 October; Nos. 21–31a were the south half, finished on 10 November

Number	*Goods*	*Prebait 1 (peak)*	*1st poisoning (corpses)*	*Prebait 2 (peak)*	*2nd poisoning (N. half) 1st poisoning (S. half) (corpses)*	*Postbait (peak)*	*Reported condition, 22 Mar. 1944*
1	Butcher	8	*	10	11	2	Some mice
2	Greengrocer and grocer	9	0	6	0	0	A few
3	Greengrocer	6	6	6	0	0	A few
4	Clothiers	3	0	0	*	*	None
5	Greengrocer	3	0	1	1 rat	1	A few
6	Butcher	6	*	6	0	0	None
7	Firewatchers' room	20	0	7	0	4	None
8	Grocer	15	0	14	0	3	A few
9	Café	2	0	3	0	7	None
10	Greengrocer and grocer	20	0	14	0	6	Many
11	Butcher	10	1	9	0	8	A few
12	Greengrocer	10	0	3	6	2	One or two
13	Butcher	33	4	21	0	5	Very few
13*b*	,,	3	1	0	*	*	None
14	,,	38	4	37	0	18	One or two
15	,,	31	5	28	0	5	A few
16	,,	19	1	5	0	3	One or two
17	Greengrocer	8	0	6	0	4	None
18	,,	31	0	16	0	0	A few
19	Confectioner	5	1	3	0	3	None
20	,,	4	0	4	0	2	Some
21	Greengrocer	..	..	9	0	5	A few
22	Pet shop	..	..	18	1	9	A few
23	Butcher	..	..	34	2	6	Just starting
24	Grocer	..	..	18	0	1	A few
25	Butcher	..	..	5	0	0	None
26	,,	..	..	5	0	1	A few
27	,,	..	..	6	0	0	A few
28	Seedsman	..	..	39	24	0	None
29	Butcher	..	..	2	0	0	None
29*a*	,,	..	..	3	0	0	None
30	Flowers	..	..	8	1 + 1 rat	0	None
31	Greengrocer	..	..	4	0	0	None
31*a*	,,	..	..	3	0	0	None

* Means that the work was not done or was abandoned on this occasion.

mash was hastily recruited for these places. The drop in take, when sausage-rusk mash was put down, was most marked at shops 5, 7, 8, 11, 13, and 14 (see Table 62 for type of shop). In shop 5 sausage-rusk mash was taken well, but in the adjoining store, which is actually continuous with the shop, was not touched. Rolled oats mash with 10% sugar was put down in the store instead of sausage-rusk mash and was immediately taken. In the main part of shop 8 sausage-rusk mash was well taken, but in the adjoining room take was very poor but recovered when rolled oats mash was substituted. In locality 7 there were similar differences. At shop 11 there was a continual

take of sausage-rusk mash in one small corner, but in the back room, where the main infestation was, there was a drop in take. Again rolled oats mash produced a recovery. At shop 14 the main infestation was in the cellar, in one part of which sausage-rusk mash was not well taken and had to be replaced with rolled oats mash, but in the other part sausage-rusk mash was taken well right through. The results from shop 13 showed the same phenomenon. At shop 10 the acceptance of sausage-rusk mash was so poor that rolled oats mash was substituted for it entirely.

Variations in take of this kind are difficult to explain, especially as some of the populations were apparently living on the same food, but the importance of baiting with the right bait is very much emphasized by these results.

Poisoning with 1% (powder equivalent) water extract of red squill in sausage-rusk mash and rolled oats mash with 10% sugar was on the whole not very successful, though at shop 16, where there had been a good take of prebait, there was about a 95% clearance. A surplus of poison points was put down (604 compared with 323 in the previous prebait) and no estimate of the take was attempted.

The results of the poisoning at shop 13 are of interest because, although a recovery in take was produced by replacing the untouched sausage-rusk mash in one half by rolled oats mash, the poisoning there was a failure compared with the rest of the store, where sausage-rusk mash had continued to be taken.

The take of rolled oats postbait in this half of the market gradually increased over a period of 12 days, when a second treatment was made with 10% zinc phosphide in this base. A teaspoonful (2·5 g.) of this poison bait was put down at each point on small slips of cardboard, which helped in cleaning up the next day.

The postbait was unavoidably curtailed, but the results after 3 days were on the whole good though still below the standard it should be possible to attain. At shop 5 one rat was killed; after the first treatment, seventeen mouse corpses were picked up, and after the second treatment a further eighteen, making a total of thirty-five.

As a result of both treatments we may say that very approximately three-quarters of the mice were killed.

A summary of the course of the poisoning with an estimate of the state of the infestation 4 months afterwards is given in Table 62 (premises 1–20).

South half. This was not so badly infested. Approximately 200 bait points were used compared with more than 300 in the north half.

Thirteen premises were dealt with. After 10 days' prebaiting with dry rolled oats, during which there was a steady rise in take, 5% zinc phosphide in the same base was put down, again on small slips of cardboard so that it could easily be cleared up. In all 174 poison points were placed.

The results of this poisoning were successful. After 11 days' postbait

with dry rolled oats only 26/186 points were taken, so that something between 80 and 90% of the mice had been killed, a greater success with a single treatment than in the north half with two. The corpses of twenty-eight adult and twelve young mice were picked up.

Details again may be found in Tables 61 and 62. The bait consumption was measured every 2 days except on 30 October and 8 November.

12

DANGERS AND PRECAUTIONS

1. THE LIMITATIONS OF POISONING FOR HOUSE MICE

In this chapter we consider briefly the special dangers that may arise from the widespread use of poisons against house mice. We insert it here as a commentary on the previous two chapters which described the actual procedure of poisoning mice in town environments. The next chapter deals with house mouse infestations in environments where food and cover coincide and are extensive, following up the division of environments into easy, moderately difficult, and very difficult according to the degree of separation between cover and food supply. We have inserted this chapter here because only in the types of locality already considered is poisoning a really satisfactory remedy. Many poisoning experiments were done by the Bureau on infestations in homogeneous environments such as corn-ricks and grain stacks in food stores, but the results were so disappointing that new methods were devised for dealing with such places. Poisoning can at times be useful, but the results (except in ricks, where other considerations still militate against the use of poison) are so patchy that they can hardly be recommended. Of course it is possible that further work might improve the technique sufficiently, but the experiments described in Chapter 14 show that the entirely new approach of fumigation, though more expensive, does at any rate ensure complete extermination which poisoning, however painstakingly elaborated, can rarely attain. Poisoning, therefore, is only recommended for the normal run of town infestations, and the details of practice have now been given. It remains to consider the special dangers that arise.

2. THE LARGE SCALE OF OPERATIONS AGAINST HOUSE MICE

The example given at the end of the last chapter of a block control campaign in the Oxford market illustrates the wide scale on which poison baits need to be disseminated, since in over twenty premises, covering probably less than an acre, no less than 604 bait points were put down. The use of special baiting implements, such as those described in Chapter 10 makes it easy and quick to lay so much bait, but we have to remember that the residue has to be picked up, and, since the amount of poison taken is small compared with the prebait, this may take a long time. Even one or two poison points overlooked may be dangerous in places where spillings and debris are swept up and sent for animal food.

Quite apart from this there is the drawback that, if small quantities of poison are left lying about, mice may sample these and become shy of that particular poison which will make them unpredictable to deal with later.

Furthermore, when we are laying baits for mice, we are seeking all the time for out of the way corners: behind sacks, upon high shelves and in the recesses of cupboards: and, if moist bait is being put down with a baiting tool, we may thoughtlessly slip baits into places from which they cannot be recovered. In one of the Bureau's experiments upon a pile of sacks, baits were slipped in between the lower row of sacks, and, since some had hardened (moist sausage-rusk was being used) the mice had moved them for small distances. These had to be laboriously collected with sticks dipped into thick grease. Paid hands doing a routine job would probably leave these inaccessible baits where they were.

Thus it is important not to bait in such tempting crannies, and, if moist bait is being used, it should be put down in a crumbly condition and should be collected again before it has dried hard.

3. RETENTION OF TOXIC QUALITIES BY BAITS

Baits which quickly become unpalatable to animals, such as moist sausage-rusk when it has dried, may still retain their toxic qualities and prove troublesome in other ways than by creating shyness, e.g. they may be swept up for animal food as mentioned above. If we are careful in picking up the baits, we can, of course, avoid this danger, but an even more satisfactory method in practice would be to use baits that are rodent-specific, e.g. red squill, or baits that automatically lose their toxic qualities in a stated period. Red squill, as shown by the information in Chapter 5, is not a very satisfactory poison to use against house mice, so that the latter alternative would be preferable if it could be attained.

Accordingly, we tested the possibility of adding some substance to zinc phosphide baits which would ensure the steady release of phosphine until they were no longer dangerous. No satisfactory results were obtained. In the first place certain hygroscopic substances, such as ferric chloride, sodium chloride, and calcium chloride, were mixed with moist sausage-rusk in concentrations of 3, 3, and 1·5% respectively and offered to mice with an equal quantity of plain rusk. The last two substances were eaten fairly well (about half as much was taken as of plain bait), so a further experiment was done in which a 5% zinc phosphide bait was mixed with calcium chloride and left for a week and then given in a free-feeding test to mice. In this time it had lost little of its toxic qualities since all were killed.

In addition to this certain cyanide salts were tested as poisons since they are notoriously unstable, but the results of free-feeding tests were discouraging (see Table 13 in Ch. 5), and after this the whole project was abandoned and we had to accept that all the standard poison baits except squill must be considered as potential dangers for quite a long period. This had of course corresponding advantages in demonstrating the keeping qualities of baits provided of course that the poisons were mixed with bases that did not become unpalatable.

4. TOXICITY OF MICE KILLED BY POISON

There is still the further danger that mice killed by poison may be a danger to domestic animals.

'Chain' poisons, such as strychnine, thallium, and α-naphthylthiourea, are obviously dangerous to use where domestic animals and wild predators or scavengers may find the corpses that lie about after a campaign. There is plenty of evidence about the first two substances mentioned. As to α-naphthylthiourea, this poison was only used once by the Bureau against mice (see pp. 174–6) and during this test two kittens were killed. Such poisons should, therefore, be avoided, especially since in the experiment quoted the result was rather poorer than might have been expected with zinc phosphide.

Apart from red squill arsenious oxide is probably the safest poison to use, since practically all the animals killed die in cover. Furthermore most mammals will save themselves by vomiting if they have eaten arsenic, so that small quantities (a poisoned mouse would rarely contain more than $\frac{1}{10}$ of a gram) are only dangerous to rodents, which are unable to vomit. Further details about this matter are given in Vol. 1, Chapter 2.

Zinc phosphide comes in rather a different category because of the marked tendency for rats and mice poisoned with it to come into the open to die. Figures from experimental poisoning of corn-ricks (see Table 68) show the relatively large numbers of corpses that may be found outside the ricks treated. Although each mouse may contain only a very small quantity of zinc phosphide a predator might eat a number of them, especially if it happened to be there when mice were crawling about rather sleepily just before they actually died. Experiments (see Vol. 1, Ch. 2) have shown that cats fed with poisoned rats may take in sufficient zinc phosphide to have fatal effects before they are ill enough to vomit.

In spite of this we have never during all our experiments known an instance of an animal dying through eating zinc phosphide poisoned mice. The reason for this is probably twofold. The small amount of poison will break down rapidly in the stomach. How long this will take exactly is not known, but a gamekeeper, who was in the habit of putting out poisoned rat corpses for killing rooks, conceived the use of zinc phosphide to be a great advance since it provided him with so many more corpses. However, his rooks ate rats at the most 24 hours dead with no ill effects. With mice the process is probably quicker on account of the smaller quantities of bait eaten (due not only to their smaller size, but also to their more sporadic feeding habits).

In the second place most predators (with the exception of chickens) are rather nice about the way in which they eat mice. Most often only the head and thorax are eaten, and if the rest of the body is taken, the stomach is removed and left. This habit has been definitely established for rats from

observations by Southern and for the barn owl, *Tyto alba*, by Guérin (1928).

It is probable, therefore, that a little reasonable care in shutting up chickens and cats during the night of poisoning is more than enough to prevent casualties occurring when zinc phosphide is used.

5. PRECAUTIONS RECOMMENDED DURING URBAN CAMPAIGNS

Various precautions, apart from general ones mentioned above, can be taken during poison campaigns, and they may be more or less stringent according to local conditions. In most places it is only necessary to use slips of cardboard or—better still—small tin trays on which to put both prebait and poison bait and to make sure that a kind of bait is used which will not scatter or clump together so that it can be carried away. If a bait such as national flour is placed directly on the floor among a dense population much of it gets smeared around and carried on the mice's fur, since it is slightly sticky and the mice will walk about over it. Rolled oats is far better since it does not cling to the fur or feet, and, for some reason, mice do not carry away even the larger flakes to eat, as they will do if whole wheat is used. This is readily verified by inspecting a pile of rolled oats that has been wholly or partly eaten; usually a neat sector is eaten away from it and the floor here is covered with characteristic fine nibblings, a sort of residual dust that always indicates the activities of mice. The care necessary to produce wet bait of the right consistency has already been mentioned.

However, if flour has to be used, bait trays will reduce the degree to which it is carried around. The ones used during the Bureau's experiments were cut out of sheet tin or zinc and the margins bent up to make a rim just under $\frac{1}{2}$ in. high. Their dimensions were roughly $1\frac{3}{4}$ in. long by $1\frac{1}{4}$ in. wide, small enough to allow the mice to feed freely without getting right into the tin.

In localities where it is particularly important that bait should not be scattered about, small bait boxes can be used. It is not possible to use these on the same scale as the underside entry boxes ('protected poison points') for rats, simply because of the large number of points that are needed. In any case a more simple type is good enough for mice, since they rarely have to be placed out of doors.

Several types of box were designed and tested by Southern, ranging from one that included a hopper to one made from two pieces of wood and a strip of sisalkraft. The latter was quite satisfactory, though of course it would not survive very rough treatment. On the other hand, since it was put together merely with large drawing pins, it was possible, when some numbers were to be used, to transport them flat and fit them together quickly on the spot. The boxes were strengthened by being made with two pieces of stout wood about $\frac{1}{2}$ in. in thickness forming the sides through which the entrance holes were pierced about $1\frac{1}{2}$ in. from the floor. This prevented the bait being carried out of the box. These entrance holes were

drilled at the ends of the pieces of wood so that when the box was put down against the wall the holes formed as nearly as possible a continuation of the runway against the wall. The dimensions were 8×8×3 in., so that the pieces of wood were each 8×3 in. and the strip of sisalkraft 8 in. wide×24 in. long, leaving an extra 2 in. for a flap to close the box. The bait was taken out for weighing by simply unpinning the top, which opened back like a flap.

The disadvantages of using such a bait box are simply the facts that it is impossible to put down sufficient to achieve the proper distribution of bait for mice, and that above a certain number they become cumbersome to transport and use. There is little difficulty in getting mice to enter them, since they do not regard new objects placed in their environment with the exaggerated suspicion that rats do. Some early experiments by Elton illustrate the difference in behaviour between the two species. He used mainly the wooden boxes that had been designed for rats; and, since he wished to know how quickly mice entered apart from whether they took any of the bait, plaster of Paris was sprinkled inside them to show up footprints. The results of his experiments are shown in Table 63.

TABLE 63. *Time before first entrance by mice into bait boxes was recorded*

Type of premises	*No. of boxes*	*No. of first entries by mice on*			
		Night 1	*Night 1 or 2*	*Night 2*	*Night 3+*
Ironmonger, office	1	1	..	..	..
Chain grocer stores	9	3	2	2	2
Private grocer stores	7	3	..	4	..
Country house	2	1	..	..	1
Museum store hut	1	1	..	..	..
Total	20	9	2	6	3

At least 45% of boxes were entered on the first night, 85% by the second night, and only 15% were unused until after this. These three include one entered on the fourth night and two for which the nature of the entry test did not actually prove that they had not entered earlier.

If bait boxes have to be used, they are most likely to be successful in localities where it is possible to intercept the mice between cover and food supply. An experiment by Southern tested the preference between open bait points and bait boxes in the food store already described (see Ch. 11). Here the mice were easy to intercept on their journeys from cover in the walls of one room to the pile of oat sacks in the next room. Along this highway, which followed the margin of the room, six bait points were placed, one of which was an open one, the rest in boxes. The figures for the daily amount of rolled oats eaten at these six points over 9 days are shown in Table 64. Point No. 4 is the open one. The mice favoured some of the points but the open one was not among them. The mice not only entered the boxes

to eat the bait, but even carried in the whole oats from the stack to eat undisturbed.

TABLE 64. *Daily take of plain bait at six points (one open, five covered) in a M.O.F. buffer depot*

Date	*Take in grammes at point*					
	1	*2*	*3*	*4**	*5*	*6*
14 Jan. . .	40	8	27	19·5	6·5	24·5
15 ,, . .	26	0	24	2·5	3	23
16 ,, . .	24·5	1	25	2	2	23
18 ,, . .	38·5	3·5	29	2·25	1·5	39
19 ,, . .	24·5	0	6·5	1	0	15·5
20 ,, . .	13·5	0	4	0	0	25·5
Total . .	167·0	12·5	115·5	27·25	13·0	150·5

* = Open point.

As a final resort, when we cannot use bait boxes and there is great danger in leaving open points, we can always fall back on red squill extract. It is possible to kill fair numbers of mice with this poison and, of course, baits containing squill can be placed in positions, from which they cannot be recovered. It is the only poison with which the inside of a stack of sacked grain or flour can be baited, since the baits can be merely dropped down from the top of the stack and left there. However, we have already shown that results with squill are unpredictable and it is always best to use zinc phosphide or arsenic wherever it can be managed. In most shops it is usually possible to arrange that the poison baits shall be put down after the premises have been closed in the evening and taken up before opening the following morning or, if the poison is to be left down for more than one night, to do the poisoning over the week-end.

However, we must again emphasize that the most important precaution to observe is that all baits shall be recoverable and recovered.

REFERENCE

GUÉRIN, G. (1928). 'Régime et croissance de l'Effraye commune *Tyto alba alba* (L.) en Vendée.' Paris.

13

POISONING HOUSE MICE IN HOMOGENEOUS ENVIRONMENTS

1. INTRODUCTION

THE most difficult environments in which to poison mice are what we have referred to as 'homogeneous' ones, in which the food supply itself constitutes a large block of cover, so that many of the mice need never come in contact with baits round the margins. In Britain there are three main types of this environment, and in all of them the house mouse can be a major pest.

First, there are the large-scale stores of cereals in which flour or grain in bags, and to a less extent in packets and boxes, are piled up into large stacks often reaching nearly to the roof and with only narrow gangways between them. Such stores are usually quite accessible to house mice since even a modern-built rat-proof structure will not exclude them, and quite often they are in possession to begin with. Such stores prove ideal ground for mice in many ways, since they are left undisturbed for long periods, lighting is dim, and the fabric of the sacks provides plenty of nesting material. When a stack is pulled down and the goods removed, most of the mice merely scamper away and enter fresh stacks.

In the second place there are the cold stores built (often a good many years ago) to take large stocks of meat and maintained at temperatures of 15° F. or lower.

The third environment of this type found commonly in Britain is the corn-rick. In this case the units are smaller and of course scattered far and wide over the country. Even so, the distribution of the house mouse is such that a very large percentage is infested every year (see results of corn-rick survey in Vol. 2, Ch. 11) and often to a very serious extent. In no habitat have higher densities of mice been discovered.

During the Second World War such environments as these constituted the greater part of the economic loss suffered from mice, and the researches of the Bureau were concentrated on the problem of how to mitigate or prevent it. A long series of experiments was carried out by Southern and Rzóska with help from Miss Laurie from the middle of 1943 to the middle of 1944 at a M.O.F. buffer depot near Oxford which housed mainly sacked grain and flour. This continued some exploratory work done at the same place by Elton. Similarly during 1943 intensive work was done by Southern with help from Miss Laurie upon the possibilities of poisoning mice in corn-ricks. In both instances the results of the research were unsatisfactory; in the case of the buffer depot because no really good reductions of the

populations were achieved and in the case of the corn-ricks because the only methods that were successful were not considered to comply with the necessary standards for safety. Accordingly during the latter part of 1944 and most of 1945 we turned our attention to fumigation in such localities. This work was done mainly by Southern and Rzóska with help from Miss Laurie and Middleton, and achieved very satisfactory results (see Ch. 14). To a certain extent therefore the work dealt with in the present chapter is out of date, but since it is important to review the difficulties of poison campaigns in such places, and to indicate the degree of success that can be achieved, the work is here summarized.

2. FOOD STORE EXPERIMENTS

Although the efficiency of poisoning here was mostly poor and extremely variable, the experiments gave valuable information upon how mice behaved towards a sequence of poison baits and to plain food after poisoning. These results, and their application to campaigns in less difficult environments are discussed in Chapter 9. Reference should also be made to that chapter for a description of the technique employed in the treatment of these stacks.

The store used for the experiments was a fairly modern building about 100 yds. long and 30 yds. wide. There was a central gangway and on either side of this bags of flour and oats were piled up in stacks, which varied in size and shape, but on an average covered a floor space of something like 35×35 ft. The oat stacks were only about 8 ft. high, being built of two layers of sacks standing upright and another layer above these placed on their sides. The flour stacks were built up to about 15 ft. with the sacks lying on their sides. The gangways between were about 3 ft. wide, though in places they narrowed to even less. The oat stacks, five in number, were placed together all at one end of the building except that there was one small flour stack in the middle of them, and the rest of this half of the building was taken up completely with flour stacks.

A preliminary test with plaster of Paris showed that mice moved little between the stacks.

Table 65 gives in summary the results of the various tests in this buffer depot. The figures for baits taken represent the number nibbled whether these were partly or wholly eaten. Usually the partial takes were a small percentage of the whole, though they tended to increase proportionately after each poisoning. However, since the peak postbait generally did not occur until several days after the poisoning, this will not affect the figures very much.

We see at once that the results are extraordinarily variable, so that there is no certainty of even moderate success. In eight of the tests (26% of the total) the results were completely negative, and only in two (10·5% of the total) was a kill of 50% or over recorded. The rest varied wildly. All that

can be said is that at the end of the experiments the populations were certainly no greater than at the start and were probably slightly less. This fact must be viewed against the known tendency for mice to increase to very large numbers in stacks of whole oats. However, there is no doubt that the process was exceedingly uneconomic, since two people and sometimes three spent an hour or more a day doing these experiments.

TABLE 65. *Course of poison trials at M.O.F. buffer depot*

Stack No.	*Peak prebait*	*1st poisoning*	*Peak postbait*	*% reduction*	*2nd poisoning*	*Peak postbait*	*% reduction*	*3rd poisoning*	*Peak postbait*	*% reduction*
Oat 3	73/100	1% sq	42/100	*42*						
,, 2	43/50	1% sq	26/50	*39·5*						
,, 5	33/34	10% z	35/37	Nil	10% z	34/39	Nil	15% A	17/35	*50*
Flour 1	39/60	10% z	46/52	Nil	15% A	40/55	*11*	15% A	34/44	*15*
Oat 4	48/50	10% z	33/59	*31*	15% A	45/58	Nil	1% sq	40/57	*11*
,, 1	57/62	10% z	50/59	*12*						
Flour 2	50/60	2% z	33/62	*34*						
Oat 2	61/75	2% z	46/75	*25*						
,, 3	50/75	2% z	14/75	*72*						
Flour 7	38/50	2·5% sq	29/50	*25*	10% A	44/50	Nil	2% z	41/50	Nil
,, 8	47/50	2·5% sq	46/50	Nil	10% A	42/50	,,	2% z	37/50	*12*

The failures do not admit of any simple interpretation. We were convinced that prebaiting was extremely successful in this habitat, so that it was all the more surprising to fail with the poisoning so consistently.

First of all, was the whole of the population attracted to the prebait? Here two experiments quoted in Chapter 2 are relevant. We dropped baits down from the top of the stack within a rectangle whose sides were 6 ft. from the edge and by observing a decrease in bait eaten at the margins, determined that some mice from at least 6 ft. within the stack regularly visited the margins. The drop in the bait taken was not very pronounced (in one case from 54 points to 46, in the other from 43 points to 31), but was sufficient to show that a proportion of mice ranged from the inside of the stack as far as the margins.

It is unlikely that there was a big enough untouched stock of mice in the middle of each stack to replace the casualties each time the margins were poisoned. On the other hand, there would undoubtedly be some replacement, which probably means that the experiments were not quite such dismal failures as they appear.

Secondly, how much attention did the mice pay to the prebait? Examination of stomach contents of trapped mice (see Ch. 8) suggested that most of their food was still taken from the oats or flour contained in the stack. Rzóska designed two experiments to throw further light upon this. After a fairly stable level had been reached in the prebait, he trapped a certain number of mice and observed the effect on the prebait level. The figures are given in Table 66.

These figures are extremely approximate. The after-trapping figure for

oat stack 4, marked with an asterisk, is a 2-day take, which is usually 10–30% above that for 1 day, so that the reduction is probably greater than shown. The estimated total is, of course, only for that part of the population that was visiting the margins. Again, therefore, the after-trapping figure may include replacing mice, and this also will lower the figure for reduction. On the other hand, mice tended to be slightly shy of the baits after the traps had been down for some days. This would affect the figures for flour stack 9, but not those for the oat stack, since here visits also, determined by plaster of Paris patches, were added to the total.

TABLE 66. *Effect on prebait level of removing mice by traps*

Stack No.	*Total points taken or visited before trapping*	*No. mice trapped*	*Total points taken or visited after trapping*	*Reduction*	*Estimated population*
Oat 4 .	47	20	30*	17	55
Flour 9 .	95	22	57	38	55

* This figure was for 2 days (see text)

Despite all this we shall not be far wrong in taking the visiting population as being of the order of fifty mice. If these mice were living entirely on the prebait they would be eating about 7·25 g. each per day (see figures for daily consumption of various foods in Ch. 3), which would mean about three baits each, since these weighed some 2·5 g. Thus in one stack the mice were taking only about one-third of their daily requirements of food from the prebait and in the other just under two-thirds.

This is a fairly substantial amount and supports the impression obtained generally that the prebait was being well taken. In most tests the consumption of prebait rose fairly rapidly to a good level (see Table 54 in Ch. 10), and there was a saturation point beyond which more baits would not increase the consumption. Naturally one of the main objects of prebaiting was to reach this point before any poisoning was contemplated.

We do not think that there was any storing of the bait, which might give a false impression of satisfactory prebaiting. The bait was crumbly and could not be carried away, and in one of the stacks, which was broken down and removed, only one or two baits were found, although it had been treated continuously for a month.

On the whole, therefore, the histories of the prebaiting seem to indicate better prospects of reducing the mice than the event showed. The explanation lies more probably in the feeding habits of the mice. Experiments already quoted (see Ch. 8) showed that introducing a gap of 1 or 2 days in the prebaiting did not increase the amount taken on the day after the gap, so that the mice turned quite readily to their old food supply and did not miss the bait. This fact, to which should be added the results of the stomach analyses cited before, proves that the bait is merely supplementary for the

mice, and that they come to it intermittently and with stomachs already half-full or more.

Under such circumstances they probably have the best possible opportunity for 'sampling' poison bait in the way suggested in Chapters 6 and 9. This means that they can probably detect the poisonous nature of the bait before they have eaten enough to kill them. At one of the stacks we inspected the bait points twice at hourly intervals after putting them down, and found that in these 2 hours as many points had already been approached as were visited during the longer interval between the last inspection and the following morning. Furthermore, once a point had been approached and partly eaten, no further take at that point was recorded the next day,

These experiments probably failed mainly because the mice were eating sublethal doses. Table 50 in Chapter 9 shows how the takes of poison bait during successive offerings of the same poison decrease.

An auxiliary cause of the failures was no doubt the movement of mice from the centre of the stack to replace those that were killed, though the extent to which this took place was impossible to measure satisfactorily. Some figures obtained by Rzóska, however, strongly suggest that this was happening. After a spell of trapping in one of the flour stacks, the traps were left down baited, but unset, and a note kept of the interval before bait was again eaten from points where mice had been caught. Table 67 gives these figures.

TABLE 67. *Intervals of time before points where mice had been caught were revisited*

Revisited after	*1 day*	*2 days*	*3 days*	*4 days*	*5 days*	*6 days*	*7 days*	*8 days*	*8+*
No. of instances	3	4	3	1	0	1	0	1	1

Thus at eleven out of fourteen sites, where mice were caught, activity was renewed within 4 days. This may have been due partly to mice that were already visiting other points, but it is probable that others were new mice that were moving in to occupy the ranges of those which had been killed.

From this discussion we must conclude that poisoning campaigns in food store stacks (mice living in the fabric of the building and coming to the stacks to feed are another matter) will not do more than temporarily check the population. Where fumigation is possible, it is far better to treat the infestations that way, even though the expense is greater: poisoning should only be used where no better method is available.

3. CORN-RICK POISONING

The method of poisoning house mice in ricks described in this section grew out of experiments on the relation of baiting to range-size done primarily for the urban work.

Other members of the Bureau had reported during field tests on poisoning rats in ricks that a small proportion of mice also usually died. This was particularly noticeable when zinc phosphide in sausage-rusk was used. Finally, A. D. Middleton tried putting teaspoonfuls of this poison bait into the mouse runs in ricks, and discovered fair numbers of corpses at threshing.

At the same time experiments on baiting house mice showed that a multiplication of bait points with quite small quantities of bait was more effective with mice than a smaller number of large points. We presumed this was due to a mouse having more chance of eating a lethal dose of poison, if it encountered baits more frequently in its foraging.

This principle was applied to ricks; whereas with rats some twenty bait points with 30 g. or more of bait are used, we tried putting down hundreds of baits each about 4 g. in weight. No prebaiting has ever been tested; the labour involved with so many baits would make it unprofitable.

In these experiments the poison bait was pushed into the runs that are found all over the outside of a mouse-infested rick. These runs are easy to find because the entrance of each is marked by a pile of chaff and kibbled grain which the mice have pushed to the outside. The first rick was baited laboriously with a teaspoon, but after this the baiting tool, described in Chapter 10, was used.

This meant not only that much time was saved but also that no poison bait was spilled about the ground, entailing waste of time picking it up or danger through neglecting to do so. Furthermore, the bait could be pushed well into the holes, so that it was not kicked out by the mice among the chaff and kibblings. In the first few experiments we placed the bait just inside the mouth of the hole, and were kept constantly picking up pieces from the ground. This trouble ceased when the baiters were pushed in for their full length.

Estimates of the results were made by attending the threshing of all ricks, collecting the corpses and counting the live ones left as they ran out.

(*a*) Comparison of different poisons

The complete results are summarized in Table 68. One quite outstanding conclusion is that zinc phosphide is far more successful than anything else tried. The lowest figure is 29% kill in rick 21, and this rick was badly underbaited. If this test is left out of account the average success with sausage-rusk and zinc phosphide (all concentrations, 7 tests) is 62·9%. Compared with this, arsenious oxide in two tests gave an average kill of 15·7% only; red squill (water extract) at 1% powder equivalent in three tests gave an average kill of only 12·8%.

The results are overwhelmingly in favour of zinc phosphide as a mouse poison in ricks, though the reason for this is obscure. The two ricks 24 and 25 together form a most interesting experiment. These were two wheat-

Table 68

Rick No.	Locality	Cereal	Date baited	No. baits	Poison	Roof baited	Baits recovered	Mice collected off rick	Date threshed	Total young	Young found dead	Total adults	Total adults killed	% adults killed
20	Begbroke	B	23 Mar.	170	2% ZP	No	..	36	3 Apr.	..	..	250	194	..
21	Sutton	W	16 Apr.	180	2% ZP	,,	48	23	21 ,,	..	..	996	288	29·0
22	Sutton	O	3	355	5% ZP	,,	56	19	7 May	53	8	292	156	53·5
23	,,	O	3 ,,	288	2% ZP	,,	78	16	8 ,,	23	12	331	139	42·0
24	Cote	W	13 ,,	443	5% ZP	,,	Few	65	20, 21 May	299	?30	653	451	69·0
25	,,	W	13 ,,	482	10% AS	,,	,,	0	21, 22, 25 May	259	Few	782	102	14·8
26	Kirtlington	W	28 May	665	0·5% ZP / 10·0% AS	,,	412	21	31 May / 1 June	250	17	766	127	16·6
27	Begbroke	W	8, 9 June	850	10% ZP	50 baits	185	321	11, 12 June	372	?70	1,996	1,373	68·6
28	Cote	W	25 June	652	10% ZP	No	Few	76	15, 16 July	104	*0	872	417	50·0
			26 ,, 13 July	308	10% ZP	,,	,,	0			10		40	9·6
29	Botley	W	8 ,,	388	10% ZP	120 baits	,,	19	29 ,,	59	13	424	370	87·0
			27 ,,	160	1% (PE) red squill extract	Yes	Many	0			2		11	20·0
30	,,	W	26 ,,	234	1% (PE) red squill extract	No	Moderate no.	1	30 ,,	53	0	215	17	6·8
31	Nr. Burford	O	19 Nov.	700	10% ZP	Yes	*c.* 50 (?)	0	26, 29, 30 Nov.	..	46	483	339	70·0
32	,,	O	20 ,,	700	1% (PE) red squill extract	,,	Few	0	24, 25 Nov.	..	5	386	40	11·6

B = Barley; W = Wheat; O = Oats; PE = Powder equivalent.

* No young were distinguishable as killed by the first poisoning.

ricks from the same crop, both rather rough and exactly the same size. They stood side by side, were baited on the same day with roughly the same number of baits in each, and were threshed consecutively. The populations were of the same order of size (653 and 782), though the second one may have received some refugees from the first. The only difference between them was that one was baited with 5% zinc phosphide and the other with 10% arsenious oxide. Yet in the first rick nearly 70% were killed, and in the second only 15%.

At first we thought that our successes were due to using moist sausage-rusk as a bait in an environment which was very dry. The above experiment, however, refutes this. Two other pairs of ricks (29 and 30, 31 and 32) show similar results comparing zinc phosphide and red squill (water extract).

(*b*) Different concentrations of zinc phosphide

The results are not very clear-cut upon this matter. The early ricks (20 and 21) which were done with 2% concentration were underbaited, and so naturally did not show good results. However, ricks 22 and 23 were used to compare the success of 2% and 5%, and, although these too were underbaited, they were strictly comparable. The results are slightly in favour of the higher concentration, and encouraged a test of 10%, which in other environments has been found to be rather too high. In ricks, however, this concentration was as successful as either of the lower ones. The best result of all (rick 29) was obtained with 10%.

(*c*) Residual populations and second baitings

Repeated poisoning was tried on rick 28, which was treated twice with zinc phosphide, the first time 3 weeks before threshing, the second time 2 days before. The corpses from each poisoning could easily be distinguished. Results altogether were poor (they have already been quoted in Ch. 9), but the results of poison-shyness are clear.

(*d*) Importance of baiting the roof

The top of a rick often contains the densest population. This is specially notable in the summer months, though this may merely be because the highest populations are found then.

In these experiments it was not possible to bait the roof unless a long ladder was at hand. However, in ricks 27, 29, 31, and 32 this was achieved. It was found easiest to separate the thatch in various places and bait underneath wherever runs or damage were visible. Often this part had numbers of rat runs and baits were placed in these.

Rick 27 was probably underbaited in the roof, but 29 was well done and this may account for the high kill. No 31 was about an average result.

(*e*) Optimum density of baits

The simplest rule to follow is to bait each active hole on the outside of

the stack. A rough estimate of these can usually be made first so that the right amount of bait can be mixed.

Where mice are few a small number of holes can easily be overlooked by the unskilled eye: at about the 100 level they are becoming fairly obvious: at the 500 level the chaff is oozing out all over, and the rick usually has the characteristic house mouse smell.

(*f*) Danger from residues of poison bait

An obvious objection to the use of zinc phosphide baits on a large scale for controlling mice in corn-ricks is the danger of the residues left. No satisfactory answer to this has been found at present, so that, in spite of the success of these experiments, it is not possible to recommend the method for general use.

No casualties at all among farm stock have been encountered during the course of these experiments, and it is in fact remarkable how little of 2,000 g. of bait put into a rick is found at threshing. In Table 68 the eighth column gives roughly the number of baits recovered in each rick. Two ricks were outstanding: No. 26, which was easily the worst, was grossly overbaited; the same in a less degree applies to No. 27.

However, in every case a few baits were found, and this is sufficient for the moment to exclude the method from general use.

REFERENCE

SOUTHERN, H. N., & LAURIE, E. M. O. (1946). 'The house-mouse (*Mus musculus*) in corn ricks.' J. Anim. Ecol. 15: 134–49.

14

CARBON DIOXIDE FUMIGATION FOR HOUSE MICE

1. INTRODUCTION

We showed in the previous chapter that it is extremely difficult to poison house mice living in homogeneous environments such as corn-ricks and stacks of sacked goods stored in food depots. So at Rzóska's suggestion we decided to investigate the possibilities of fumigation using carbon dioxide as the fumigant as it is fairly easy to obtain, not directly poisonous, and does not affect the grain in any way.

The experiments fall under three main headings: first, those carried out in the laboratory to determine the toxicity to mice of different concentrations of carbon dioxide; secondly, field tests in a food store in Oxford to determine whether the necessary concentration could be built up under conditions which would be faced in practice; and thirdly, field trials concerned with the fumigation of mouse-infested corn-ricks with carbon dioxide.

2. LABORATORY EXPERIMENTS

(*a*) Technique

The following technique was adopted for determining the toxicity curve for carbon dioxide given in Fig. 18 which is based on sixteen experiments involving a total of thirty-two mice. A 10-litre aspirator jar was used in all the experiments. Enough solid carbon dioxide was weighed out to give the concentration required and this was tipped into the jar. When this had volatilized, the gases were mixed by continual inversion and shaking and samples were withdrawn from top and bottom of the jar for determination of carbon dioxide content until an even mixture was obtained.

We made our determinations as follows: 5 ml. of the mixture were withdrawn from the jar into a hypodermic syringe and then bubbled through a 10% solution of caustic soda into an inverted measuring cylinder. The volume was read on the measuring cylinder and the difference, representing the amount of carbon dioxide absorbed, noted.

As soon as a satisfactory mixture of carbon dioxide and air was obtained in the jar, two or three mice from the wild stock maintained by the Bureau were lowered each in a small wire-netting cage to the bottom of the jar. Room temperature was noted and a carbon dioxide determination made to check any loss incurred while the mice were being put in. In concentrations above 16% the mice were kept under continuous observation until they

died. For concentrations below 16% it was difficult to note the results consistently. One of the following methods was adopted: either the mice were left in for a very long period (e.g. 18 hrs.) until it was reasonably certain that they could tolerate the concentration indefinitely (this was unsatisfactory because of accumulation of carbon dioxide and decrease of oxygen and was only done once); alternatively the mice were left unobserved after

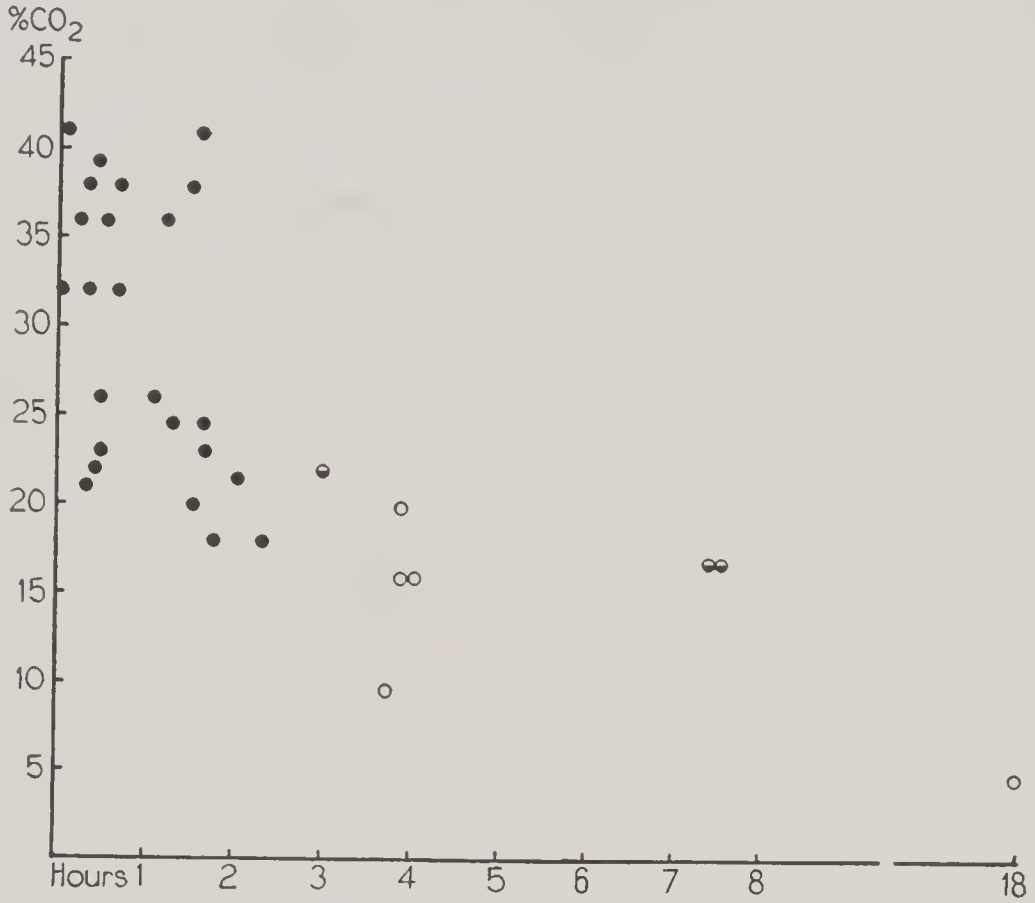


FIG. 18. Toxicity of carbon dioxide to house mice.
● died; ◒ taken out alive; failed to recover; ○ taken out alive; recovered.

2–4 hours except at less frequent intervals, and the time of death determined within an hour or so; or the mice were observed for a certain time, then removed to see whether or not they recovered. These different circumstances are all noted in Fig. 18, but the part of the toxicity curve below 20% is not of great importance and the main issue is unaffected.

(*b*) Results

Fig. 18 shows the results obtained in these experiments. The points on the curve represent times of death. This errs on the safe side, because some time before this the mice would be unable to recover even if restored to the air. After the initial exaggerated hyperpnoea one of two things usually happened: either the respiratory rate fell evenly and rapidly or it fell less quickly and with a marked flattening out of the curve before death. This difference is shown in Fig. 19.

The second alternative occurred more frequently in lower concentrations, but there was great individual difference among the mice, and sometimes both types of curve occurred in the same experiment (Fig. 19).

Two things are clear; first that the resistance of wild house mice to carbon dioxide is high, concentrations up to 10% being tolerated almost

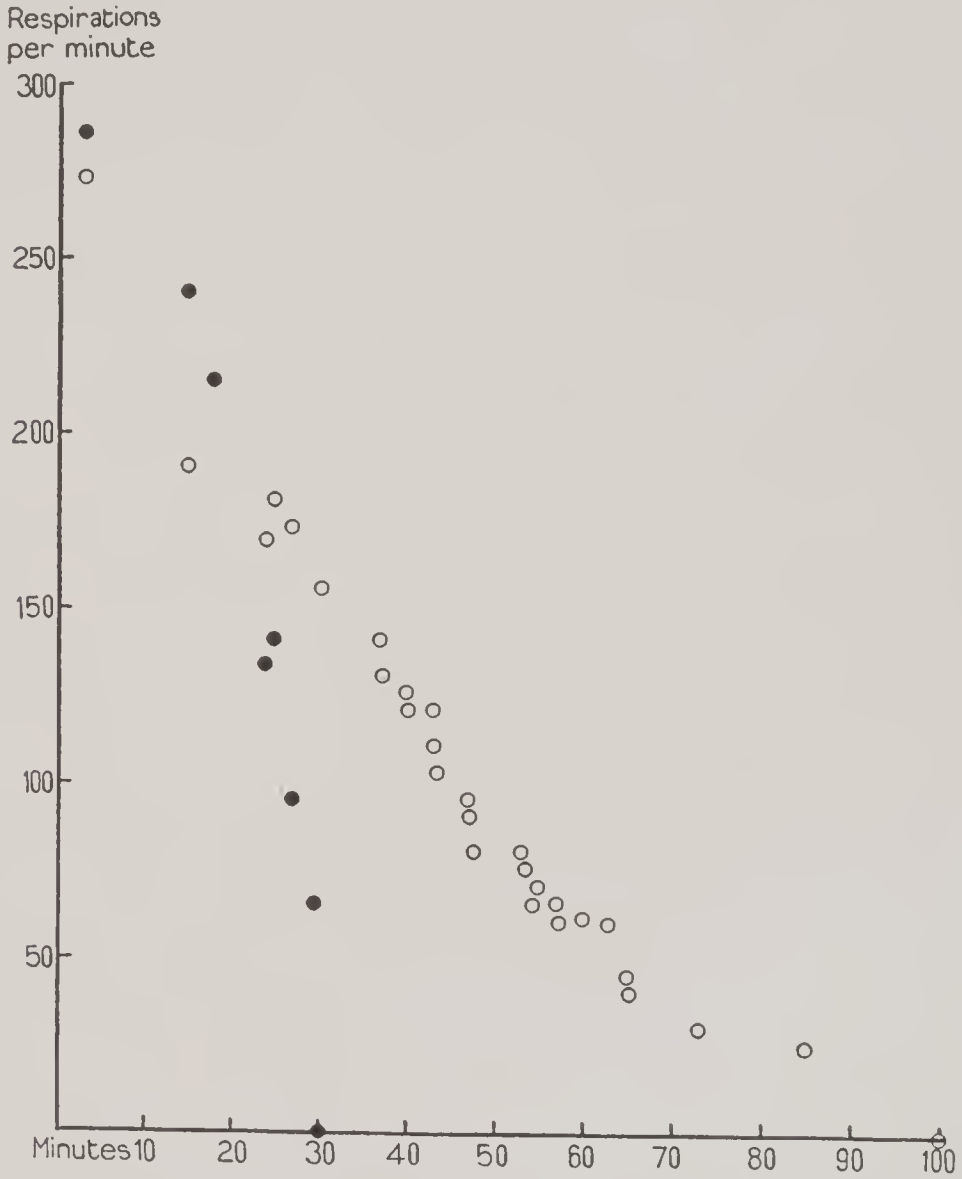


FIG. 19. Respiration rate of house mice in 23% carbon dioxide.
● ♀ 18·0 g.; ○ ♀ 15·5 g.

indefinitely; secondly, that there is remarkable individual variation in this resistance. As to the first point Flury and Zernik (1931) quote the following: Kunkel (1901) states that for animals other than man in normal oxygen concentrations 10% carbon dioxide is tolerated indefinitely, 30% causes narcosis in one to several hours, and 60% kills in 15–20 minutes. Prausnitz and Schultzik (1928) state that for mice 10% has no effect, 25% narcotizes quickly, 50% may be survived up to 1½ hours, and over 60% causes death quickly, while Barbour and Seevers (1943) found that albino rats survived

10% indefinitely, a few died in 15%, and four out of five died within 4 days in 20%, all were dead within 36 hours in 28% and within 6 hours in 50%.

These results, though sparse, confirm the curve given in Fig. 18. Death is not certain in concentrations up to 20%; on the other hand, above this point the present data show rather quicker results than indicated in the literature. At concentrations above 20% twenty mice died in less than 2 hours, one in slightly over 2 hours, and one survived 3 hours, but died subsequently. Above 22% no mouse survived longer than $1\frac{3}{4}$ hours. As to individual variation it is notable how little difference there is in the range of times at, say, 23% and 40%, so that there is little advantage for the purpose of practical fumigation in pushing up the concentration to the latter level (see Table 69). The effect of the higher concentrations is seen more in the distribution of the times of death.

TABLE 69. *Distribution of times of death at higher concentrations*

	Number of mice dying	
Concentration	*Before 45 min.*	*45–105 min.*
23–30%	3	4
32–42%	9	3

3. FIELD TESTS IN AN OXFORD FOOD STORE

(*a*) The experimental stack and gas-proof cover

This stack was built in one of the Oxford food stores and consisted of fifty-two sacks of oats, each weighing about 150 pounds. Overall dimensions were $9 \times 9 \times 4\frac{1}{2}$ ft. with a volume of 364 cu. ft. The sacks were piled up in two layers on top of wooden planks laid on a tarred gas-proof tarpaulin which was spread over the concrete floor. During the first test the tarpaulin was folded up to provide a gas-proof 'case' over which the 'lid' of the cover was drawn. This was done to prevent gas leaking from the bottom, but the precaution was found to be unnecessary and was discontinued. During some of the experiments mice in small wire-netting cages were distributed in different parts of the stack.

All the field tests described below were done with a special cover made out of balloon fabric supplied by the Ministry of Aircraft Production. This cover was made to fit the experimental stack and was wider at the bottom than at the top to allow it to be pulled over the stack easily and quickly. The strips of material were joined together with rubber solution, which gave a join strong enough for experimental purposes. The procedure adopted was to put the cover over the stack first, then to fold it right back until it lay along one edge of the stack. In this way the carbon dioxide could be distributed close to its rolled-up edge and the cover rolled forward progressively

as the carbon dioxide was scattered. A margin of about 2 ft. was left so that the cover trailed on the floor and this was used for sealing the lower part of the cover to the floor so as to make as gas-tight a fit as possible. Where the goods (as in this case) were stacked on a concrete floor without cracks, the task is easy, since it is sufficient to put sandbags on the skirt of the cover to press it against the floor. Where the floors are wooden or cracked it will clearly be more difficult and it would be advisable to stack goods on a layer of sisalkraft or some similar substance. Since the cover is gas-proof the complete sealing at the top prevents air entering and so the carbon dioxide mixture is held within even if sealing at the bottom is not perfect. Experiment 7 (Table 70) shows the effect of cutting quite a small hole in the top of the cover.

(*b*) Sampling the concentration

This was done in the first series of experiments through glass tubes pushed into the stack at different levels and later by lead capillary tubing of 2·5 mm. outside diameter. The gas mixture was drawn in this way from the top, middle, and bottom of the inside of the stack. The outer ends of the tubes were carried out under the skirts of the cover and could be connected with the hypodermic syringe for drawing out 5 ml. samples. The concentration of carbon dioxide in these was determined in the way described above. Care was taken to clear the connexions by withdrawing 15 ml. before each sample.

(*c*) Carbon dioxide supply

Apart from some preliminary laboratory tests the carbon dioxide used was all in solid form, supplied to the market by Imperial Chemical Industries Ltd. under the name of 'Drikold'. Large insulating containers, holding about 100 pounds are also supplied and the four blocks which make up the 100 pounds keep without serious loss for 48 hours after they have been received. Two grammes of this carbon dioxide 'snow' give about 1 litre of gas, 1 kilogram about 500 litres. These 25-pound blocks should be handled with care and not allowed to touch the skin, otherwise the low temperature creates injuries similar to burns. Leather gloves are sufficient protection. These blocks were placed in sacks and hammered with a wooden mallet into small pieces, leaving nothing larger than a walnut. Then the powder was distributed on top of the stack as quickly and as evenly as possible, and the cover rolled over it as described above.

(*d*) Results

Seven experiments done from 5 October to 6 November 1944 were carried out with the balloon fabric cover. In each case the preliminary work followed the same sequence; breaking up the carbon dioxide snow and distributing it on top of the stack, pulling the gas-proof cover over (these two

processes must be done very quickly or a great deal of the gas is lost); and finally sealing it down on to the floor with sandbags. The average time for all this with two people was half an hour, but the hammering up of the carbon dioxide only took about 5 minutes. After this the only thing that remained to be done was to withdraw samples at certain intervals and determine the concentration of carbon dioxide.

TABLE 70. *Results of field experiments*

Expt. No.	*Wt.* CO_2 *(lb.)*	*Max. concent.*		CO_2 *determinations (%)*				*Persistence of solid* CO_2	*Remarks*
		%	*After (hrs.)*	*hrs.*	*Top*	*Middle*	*Bottom*		
5 (24 Oct.)	12	28	4½	2	26	26	26	+	Temp. 57° F. 6 mice in bottom of stack. Removed after 2 hrs.; all dead
				4½	28	28	28	+	
				6½	26	28	28	−	
				9½	24	26	25	..	
				24	20	20	20	..	
				48	11	12	12	..	
6 (31 Oct.)	13	26	3	1	20 (18)	20 (−)	21 (21)	+	Figs. in brackets are chemical determinations made by D.S.I.R. Temp. outside stack 54° F., inside, 52° F. 6 mice in bottom of stack, 3 examined after 1 hr. all dead; others after 24 hrs. all dead
				2	24 (23)	24 (25)	24 (24)	+	
				3	26 (24)	26 (25)	26 (24)	+	
				24	18 (20)	19	19 (20)	−	
3 (6 Oct.)	13	24	3	¾	20	..	18	..	Four mice put in stack; all these + 2 others dead at end of experiment
				3	23·5	..	22·5	..	
				23	14	..	13	..	
2 (5 Oct.)	16	28	5	½	19	..	22	..	Underlying tarpaulin folded up; 9 mice all dead at end of experiment
				1½	22	..	23	..	
				2½	24	..	26	..	
				5	28	..	26	..	
7 (2 Nov.)	17·5	34	4½	¼–½	11	12	16	..	Temp. 42·5° F. After 26 hrs. a slit was made in top of cover. Concentration fell 2–3% in ¼ hr., 2–7% in 4 hrs.
				2	26	30	30	..	
				4½	30	32	34	..	
				6½	30	30	30	..	
				8½	32	31	30	..	
				26	26	26	26	..	
4 (18 Oct.)	22	36	4	2	30	..	29	..	..
				4	35	..	36	..	..
				24	28	..	30	..	..
				28	27·5	..	30·5	..	..
				71	10	..	11	..	..
8 (6 Nov.)	28	44	11½	1½	26	21	29	+	Temp. 49° F. 14 mice released, 22 corpses recovered. The middle sampling tube was pushed into the centre of an oat stack
				5½	39	39	38	−	
				12	44	44	38?	..	
				24	43	43	42	..	

In Table 70 the tests are arranged in ascending order of the quantity of carbon dioxide used. In columns 3 and 4 the maximum concentration recorded and the time from the start of the experiment are given. Note, however, that not all the tests extended over 24 hours and in most cases the

sequence of readings will not necessarily reveal the highest concentration reached. In experiments 5 and 7 the maximum is shown most accurately. The last column in the table gives the results of putting wild house mice into the experimental stack during the tests, either in small wire-netting cages or merely distributed free in the stack. Where some were examined before the experiment ended, the cages were placed at floor level and pulled out from beneath the skirt of the cover with strings: thus escape of

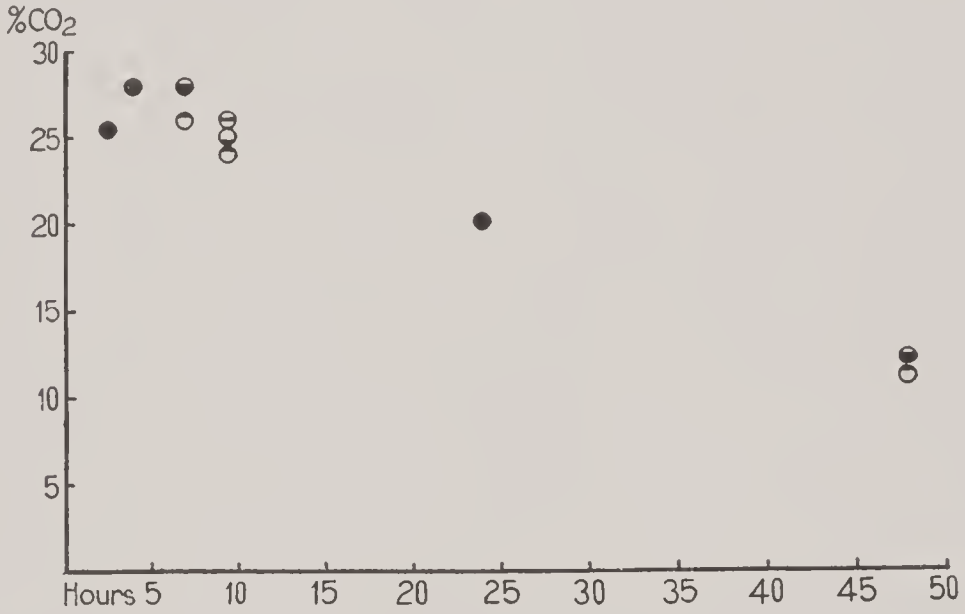


FIG. 20. Carbon dioxide concentration curve in experimental stack with 12 pound Drikold (experiment 5).

◓ top of stack; ⊖ middle of stack; ◒ bottom of stack.

gas was negligible. On no occasion were any live mice noted when the cover was removed, and after the last experiment, when the stack was unbuilt, an accumulation of corpses was found (17 newly killed and 5 belonging to an earlier test) and no live mice seen. The results of taking out some of these mice during the course of the experiments showed that death occurred quite early; of three that were removed at the end of 1 hour from a concentration which had built up to 20% in that time, all were dead; of six removed at the end of 2 hours all were dead.

Generally the progress of volatilization is quick: where early readings were done, concentrations of 12% were recorded in 10 minutes and 16% in 25 minutes. In other experiments 19–22% were recorded in $\frac{1}{2}$ hour, 18–20% in $\frac{3}{4}$ hour, and 20% in 1 hour. The rise of the concentration was followed with some accuracy in experiment 5 (12 lb.) and 7 (17·5 lb.), and the results are shown graphically in Figs. 20 and 21. In both the curve rises steeply and reaches a peak in about 4–5 hours, and after that the concentration falls slowly. The rate of loss varied slightly (less than 0·5% per hour for 38 hrs. in experiment 5 (Fig. 20) and just over 1% per hour for 22 hrs.

in experiment 6 (Fig. 21)), but was never a factor threatening the success of the tests.

A somewhat different form of curve was found in experiment 8 where, after reaching 44% within 10 hours, the concentration remained at this level for about 15 hours. When the test was ended at 25 hours there was still a concentration of 42–43% inside the cover. This test was made with the biggest quantity of carbon dioxide and there may be some buffering

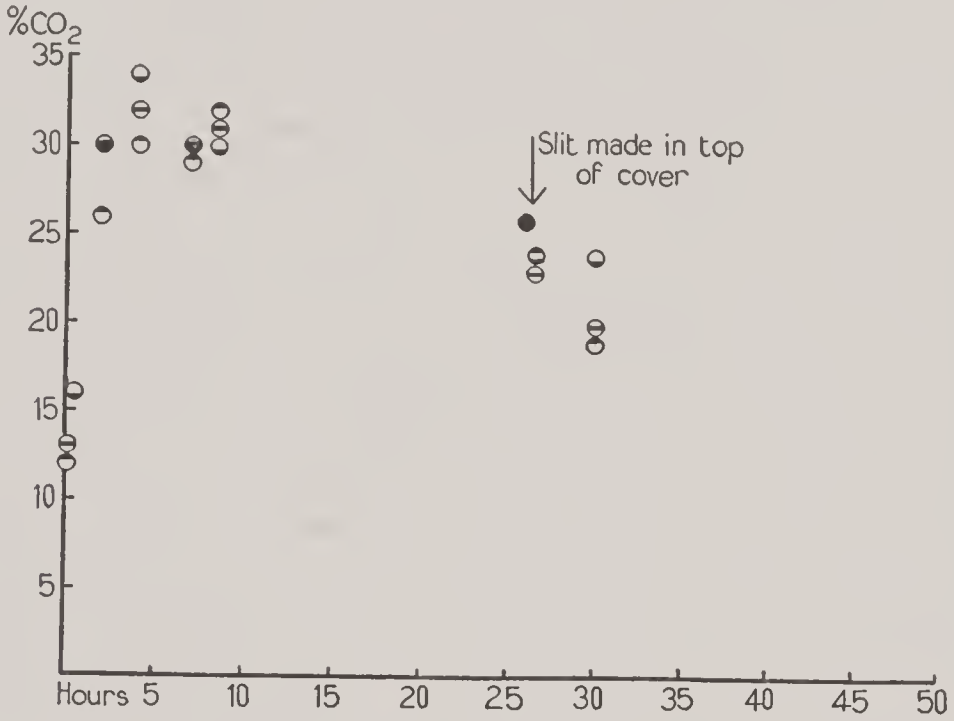


FIG. 21. Carbon dioxide concentration curve in experimental stack with 17½ lb. Drikold (experiment 7).

◓ top of stack; ⊖ middle of stack; ◒ bottom of stack.

effect of a high concentration which slows down volatilization. In all tests (6 out of 7), where readings were continued for 24 hours or more, the concentration never fell below 14% after 24 hours; with the higher doses of carbon dioxide (experiments 4, 7, and 8) concentrations were maintained at a level between 26 and 43% after 24 hours.

(*e*) Discussion

Although some of the tests were terminated before 24 hours and although the sequence of readings will not always reveal the highest concentration reached, the maximum is clearly related to the amount of Drikold (Table 71).

The following would therefore be roughly the quantities to use per 1,000 cu. ft.; 35 pounds to give a maximum concentration of 26%, 59 pounds to give 36%, and 74 pounds to give 44%. It seems probable that fumigation with the lowest dose of 35 pounds per 1,000 cu. ft. for a period of 4 hours should be quite sufficient to ensure complete killing of the mice, under a gas-proof cover. The tests show that with a cover of gas-proof balloon

fabric there should not be the slightest difficulty in maintaining a lethal concentration for the time needed to kill all the mice.

TABLE 71. *Relation of maximum concentration to initial dose of carbon dioxide*

Dose of CO_2	*Peak concentration in 364 cu. ft.*
lb.	%
12–14	24–28
16–17·5	28–34
22	36
28	44

The space of 364 cu. ft. which represented the volume of the experimental stack would of course be largely occupied by the goods to be fumigated. However, apart from the variation of the space between the sacks due to their close or loose packing, the variation for this kind of commodity inside the sacks is not likely to be great. Jones (1943) gives some figures for the percentage of air space in various foods; grains vary between 40 and 60%, while plain white flour may be as much as 66%. There is nothing here to suggest that the doses recommended above will need modification within this range of materials.

Similarly the conditions of temperature under which these experiments were done (42–57° F.) are probably varied enough to suggest that little attention need be paid to this factor at any rate within the British Isles.

Diffusion is quick, since the heavy carbon dioxide sinks down through the stack. The evenness of the figures at different levels confirms this. Sometimes initial readings showed a higher percentage at the bottom, but later these slight variations were evened out. In experiment 7 a slit 1 inch in length was made in the top of the cover after 26 hours: in the following four hours the percentage at the top fell by 7%, at the middle by 6%, and at the bottom by 2% only. This shows that replacement of the carbon dioxide by air had begun from the top. The slit was meant to test the effect on the efficiency of fumigation of flaws in the cover, and it seems from the result that these might be considerable if the cover is not kept in good repair.

The penetration of carbon dioxide was tested in experiment 8 by pushing one of the sampling tubes into the middle of one of the sacks among the oats. There was a slight lag to begin with, but penetration was very quick and the readings from the middle of the sack quickly reached the same level as those made from the other two sampling tubes, which were laid as usual between the sacks.

The advantages of carbon dioxide may be summarized as follows: firstly, the fumigation is simple and easy to carry out with unskilled labour; secondly, there is no direct danger either to the goods or to the workers;

thirdly, there is no unpleasant smell; and, lastly, it is as cheap as and more efficient than other fumigants.

(*f*) Points in the practical application of the results

A few points should be mentioned with regard to the practical application of carbon dioxide. Care must be taken not to use carbon dioxide in any place that forms a well, e.g. an underground cellar or barge. Jacobs (1941) quotes a case where three people were killed while fumigating the hold of a ship. Wherever there is no escape at the lowest level, the heavy gas will flow downwards and accumulate. Similarly care should be taken where there is such a well, e.g. a stoke-hole, near the goods to be fumigated. Jacobs gives figures which show that man is much more quickly affected by carbon dioxide than other animals. A concentration of 10% produces unconsciousness within a few minutes. Lower concentrations produce a great increase in breathing rate (up to 300%) and any effect like this should be watched for. All the field experiments described above were carried out without the slightest signs of discomfort.

The only modifications needed in stacking goods liable to infestation by mice would be (*a*) gas-proof floor, i.e. concrete or covered with sisalkraft; (*b*) surrounding floor space to be kept clear for preferably 2 ft. all round each stack; (*c*) stacks to be built in the open, not around pillars, girders, or radiator pipes; (*d*) stacks to conform approximately to certain standard sizes so that covers can be kept in stock which will fit them all.

4. FUMIGATION OF MOUSE-INFESTED CORN-RICKS WITH CARBON DIOXIDE

These investigations fall into two parts: first, those in which solid 'Drikold' carbon dioxide was used, and, secondly, those concerned with the use of liquid carbon dioxide from cylinders. The first tests using 'Drikold' were carried out in Northumberland in April 1945 as the small round ricks, which are common in the north of England, were most suitable for the purpose. The experiments with liquid carbon dioxide were carried out near Oxford.

(*a*) Solid 'Drikold' carbon dioxide

(i) *Methods*

The equipment needed for gassing ricks with solid carbon dioxide is as follows:

(1) Gas-proof cover for rick.
(2) 6 ropes (about $\frac{3}{8}$ in.) about 18–20 yds. long.
(3) 8–10 smooth stakes about 5 ft. long.
(4) 2 or 3 bags about 20 in. by 20 in., preferably of heavy canvas.
(5) Very small hand shovel.

(6) Heavy wooden mallet with a short handle.
(7) 2 ladders, long and short.
(8) 2 spades.
(9) Supply of thick string.
(10) Leather gloves for handling CO_2 blocks.
(11) Platform of thick planks about 4 ft. by 2 ft. for smashing CO_2 on.

For the purpose of the field trials carried out in Northumberland, a special shaped cover, designed to fit the small round ricks commonly built there, was made out of gas-proof balloon fabric. It would cover a rick just over 3,000 cu. ft. and it weighed 62 pounds.

The procedure adopted in the food store of scattering broken carbon dioxide over the top of the rick and then covering it, proved impracticable owing to the time taken to fit the cover over the corn-ricks. A narrow trench about 6 in. deep was first of all dug round the base of the rick. The cover was then put over the rick and the bottom buried in the trench by stamping earth over it, which made a reasonably air-tight seal. A rope was tied firmly round the whole rick at the height of the eaves in order to prevent lumps of carbon dioxide rolling down the thatch on to the ground. This is important as carbon dioxide is heavier than air. The 25-pound blocks of carbon dioxide were smashed up in small hessian bags with a wooden mallet on stout planks laid on the ground. The smashing was continued until the largest particles were about 1 in. in diameter. A lot was, of course, reduced to powder during the process. The bags were carried to the top of the rick as quickly as possible and the carbon dioxide scattered inside the cover with a small hand shovel through a circular hole about 3 ft. in diameter which was cut in the top of the cover. When all the carbon dioxide was inserted, this hole was drawn together and tied firmly with cord in the manner of tying a sack. With one person smashing blocks and one scattering the lumps at the top of the rick, this routine was quite practicable but rather laborious. There was some loss of carbon dioxide in the smashing process and in carrying the bags to the top of the rick, but little in the scattering, as that was done under the cover. Special bags of strong fabric would be an advantage, as hessian proved to be of too loose a texture and was quickly torn by hammering especially in wet conditions when the bag froze solid and was torn by each blow of the mallet.

Normally three people were available for putting on and taking off the cover, which is probably the optimum number for this routine in practice, although it can be done by two. The special shaped cover used for these experiments was folded by rolling the outside (bottom) edge continuously towards the centre (peak), so that when it was placed on the peak of the rick the roll fell away down the thatch and covered the rick providing it was a loose fit. To take it off, the cover was rolled up from the bottom to the peak. This was easy up to the height of a man's reach, using a number

of stakes pushed into the rick to support the roll as it progressed upwards. The final rolling from the eaves to the peak was more difficult but was greatly helped by three or four ropes tied to a stake in the peak under the cover, passing these under the roll and hauling on them simultaneously from the peak. The following are the average times taken to carry out the various stages in the procedure, using a team of three. There is no doubt that these times would be reduced with practice and further experience.

	Time (min.)
(1) Digging trench, preparing pull ropes, getting folded cover to peak, unloading cases of 'Drikold', bags, &c.	40
(2) Putting cover on rick, sealing base, roping	20
(3) Breaking six blocks 'Drikold', scattering on top of covered rick, and tying top	30
(4) Taking off cover, collecting dead mice, and clearing up site	30
	120

The cover was normally left in position for 4 hours after the carbon dioxid was inserted, this being the time estimated to make certain that all mice would be killed by a 25–30% concentration gradually built up by the solid carbon dioxide.

(ii) *Measuring technique*

In order to determine the concentration of carbon dioxide throughout the rick, samples of the gas mixture were obtained in the following way. Lead capillary tubing of 2·5 mm. outside diameter was pushed into the rick at different levels. In order to facilitate pushing the tubes into the rick they were attached to strong wooden or metal stakes. The best were made out of 5–6 ft. lengths of metal tubing used for carrying electric wire. Part of the capillary tube was threaded through the inside of the metal tube and drawn out at the opposite end. The free end of the capillary tube was brought out from under the cover and so could be connected with the hypodermic syringe used for drawing out the samples. The method of determining the concentration of carbon dioxide was the same as that described already in the sections dealing with laboratory experiments and field tests in an Oxford food store. Wherever possible three sampling tubes were put into the rick, one near the eaves, one in the middle, and one at the bottom, to depths varying from 3–5 ft. inside the rick.

(iii) *Field trials and results*

Six experiments using solid carbon dioxide were carried out on mouse-infested ricks in Northumberland. The results are given in Table 72.

It will be seen that in three ricks (Table 72, Nos. 1, 2, and 4), all the mice were killed while in the other three, although many dead mice were found, some were still alive when the cover was taken off. These quickly recovered

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TABLE 72. *Results of experiments using solid carbon dioxide ('Drikold') on mouse-infested corn-ricks 11–17 April 1945. Threshing was done within 2 days of fumigation*

No. expt.	Size rick (cu. ft.)	Approx. wt. CO_2 'Drikold' used			% CO_2 at 3 different levels; 100–170 cm. (3–5½ ft.) inside rick				Results					
									No. mice found dead					
		lb.	lb./1,000 cu. ft.	g./cu.m.	Time* (hrs.)	Eaves	Middle	Bottom	Outside	Inside when threshed	Total	No. live mice	% of total found dead outside	% kill
1	2,713	190	70	1,121·7	1½	35	31	34	..	..	..	..	..	..
					4	38	38	37	121	173	294	0	41	100
2	2,967	190	64	1,025·7	1	28	22	28	..	..	..	..	..	..
					2	30	22	32	..	..	..	..	..	..
					3	38	28	35	..	..	..	..	..	..
					4	36	28	36	88	23	111	0	79	100
3	3,034	95	31	501·5	1	13	19	18	..	..	..	..	..	..
					2	19	19	20	..	..	..	..	..	..
					3	20	23	21	..	..	..	..	..	..
					4	20	22	20	..	..	..	..	..	..
					5	19	18	22	73	1+	74+	Few	*c.* 80	*c.* 75
4	2,570	140	55	872·5	2¾	30	32	32	..	..	..	..	..	..
					4	26	30	28	137	69+	206+	0	*c.* 66	100
5	2,458	100	41	651·6	1	25	20	22	..	..	..	..	..	..
					2	24	25	23	..	..	..	..	..	..
					3	26	25	25	..	..	..	..	..	..
					4	24	22	25	37	24	61	Few	*c.* 60	*c.* 80
6	1,488	70	47	753·5	1¼	..	26	..	..	..	..	..	..	..
					1¾	..	27	..	..	..	..	..	..	..
					2¾	..	28	..	..	..	..	..	..	..
					3½	..	27	..	..	..	..	..	..	..
					4	..	26	..	350	Not known	350+	Few	?	?80–100

* These figures are the times at which readings of the concentration of CO_2 gas were taken after all the solid CO_2 had been scattered on top of the rick and left under the sealed cover.

in the fresh air. The lowest amount of solid carbon dioxide which gave a complete kill was 872 g. per cu. m. (55 lb. per 1,000 cu. ft.), while 753 g. per cu. m. (47 lb. per 1,000 cu. ft.) failed. It appears therefore that the minimum concentration necessary would be obtained by an amount of solid somewhere between these figures, the difference between these figures and results from the experimental stack are doubtless due to working in the open and taking longer to apply the carbon dioxide.

The peak concentration of carbon dioxide (taking the average of the three different levels) appears to be reached at $2\frac{3}{4}$–3 hours (Table 72). These averages for the three failures (Nos. 3, 5, and 6) are 21, 24, and 28% respectively. For No. 4 the average at $2\frac{3}{4}$ hours was 31%. Nos. 1 and 2 have unnecessarily high concentrations. These figures indicate that the minimum killing concentration for an exposure of 4 hours is between 28 and 31%. Air temperatures during these field trials varied from 7–15° C. and those measured in the sun were considerably higher, up to 31° C. It was often windy and on some days wet. However, it seems reasonable to assume that the volatilization of 'Drikold' will not be affected by the normal range of temperatures in this country.

The most surprising result of the gassing was the large number of mice found dead on the outside of the ricks. On removing the cover, these mice were lying in heaps around the base of the rick. From 41–79% of the total population were found dead outside after successful gassing. Nests of young mice, found in the soil under some of the ricks were all dead.

(*b*) Liquid carbon dioxide from cylinders

Some field tests were carried out on the use of liquid carbon dioxide from cylinders as it was thought that in this form it might be more convenient to handle than the blocks of solid 'Drikold' described above. The results of these experiments carried out on four mouse-infested ricks are given in Table 73. The main problem which had to be overcome in this case was the supply of carbon dioxide from the cylinders into the ricks; in most instances this was considerably delayed by freezing in the connexions, and the procedure is not one to be recommended.

A much larger gas-proof cover was, of course, needed for the fourth rick, which was about the normal size found in England, and this cover was made in the form of a simple square sheet of balloon fabric 64×64 ft. which weighed about 3 cwt. 3 qrs. This sheet was folded and rolled up round an iron bar, the ends of which fitted into two supports which could be driven into the ground. A handle was attached to one end of the bar in order to turn it round, like a windlass. Two men on the roof were able to haul the cover up from the windlass by the free end until it lay across the middle of the roof with both ends hanging down over the sides. From this position it was quite easy to unfold the rest and drape it over the whole rick. The bottom was buried in the usual way, by stamping earth over it in the trench

TABLE 73. *Results of experiments using cylinders of liquid carbon dioxide on mouse-infested ricks, 16 May–26 July 1945*

No. expt. and date 1945	*Size rick (cu. ft.)*	*Approx. wt. liquid CO_2 used (1 cylinder = 28 lb.)*			*% CO_2 at 3 different levels; 122–52 cm. (4–5 ft.) inside rick*				*Results*					
									No. mice found dead					
		lb.	*lb./1,000 cu. ft.*	*g./cu.m.*	*Time (hrs. after taps opened)*	*Eaves*	*Middle*	*Bottom*	*Outside*	*Inside when threshed (date)*	*Total*	*No. live mice*	*% of total found dead outside*	*% kill*
1	1,629	112	69	1,101·2	1	40	25	22	..	..	..	..	..	..
					1¾	38	39	33	..	..	..	..	..	..
16 May		Emptied in 2 hrs.			2½	37	35	36	..	22 June,	..	..	..	..
					3½	37	36	38	82 (1 rat)	15	97	17 (1 rat)	71	85
2	1,270	112	88	1,412·5	1½	31	32	33	..	23 June,				
		Emptied in 20 min.			3	31	30	32	16	20–30 (1 rat)	*c.* 45	Few	*c.* 35	? *c.* 80
30 May														
3	1,270	112	88	1,412·5	1	25	41	30	..					
		Nearly emptied in 15 min.			2	35	31	33	..	23 June,				
11 June					3	31	31	32	80	*c.* 12	*c.* 92	,,	*c.* 87	? *c.* 90
4	6,219	336	54	866·6	10 min.	3	..	3						
					45 ,,	6	..	15						
26 July		Emptied in 2½ hrs.			1 hr.	1	5	18						
					1¾ hrs.	5	16	25	..	10 Aug.,				
					2½ ,,	15	20	28	250	many	?	0	?	100
					21 ,,	16	18	20						

which had been dug round the rick, thus making a reasonably air-tight seal. It would be an advantage if the cover was octagonal. This would avoid excess material at the corner folds which is awkward to bury. In taking the cover off it was first pulled up from the two ends of the rick on to the roof with the aid of some rope attached to the four corners, and then folded across from the ends to the middle. The end of the cover nearest to the windlass was wound round the iron bar and the rest rolled on to it by turning the handle.

The experiments using cylinders of liquid carbon dioxide showed that it was possible to obtain and maintain a sufficiently high concentration of carbon dioxide inside the rick to kill the mice but that the practical application of it was laborious. The rather complicated apparatus (long lengths of copper tubing, cylinders, valves, screwed joints, &c.) make the whole operation very vulnerable to accidents and mistakes in the hands of unskilled operators. The difficulty due to freezing of the expanding gas and consequent blockages was not completely overcome by any of the methods tried for conveying the gas from the cylinders to the rick. The only point in favour of the cylinders is that they can be stored for an indefinite period, whereas 'Drikold' must be used within 48 hours of receipt if serious losses are to be avoided.

The general conclusion from experience of the two methods is definitely in favour of the solid, since it requires less equipment and is more reliable with unskilled labour. The cost of either liquid or solid carbon dioxide is, however, at present, so large for the treatment of a single rick that it is doubtful whether the project can be made sufficiently economic to interest farmers. It should, however, be borne in mind that the field populations of house mice are concentrated in the corn-ricks during the winter months, so that any large-scale control by these methods might have a very considerable effect upon the whole population lasting for more than a year. This would lower the cost of control. Further experiments are, however, required to ascertain this.

The successful manipulation of the gas-proof cover as a means of enclosing a corn-rock completely is probably the most important result of these experiments. If a different and cheaper gas could be used in a simple way, utilizing the same method of covering, the costs of the whole operation might be halved.

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ROUGH KEY TO PROCEDURE WITH HOUSE MOUSE INFESTATIONS

1. (*a*) Environment 'difficult'—bulk food stores, cold stores, corn-ricks . 2
   (*b*) Environment 'medium or easy'—food and cover mixed up—shops, houses 4
2. (*a*) Emptied of contents periodically. Treat when empty . . . 9
   (*b*) Never emptied 3
3. (*a*) Possible to fumigate. *Employ firm which specializes in this.*
   (*b*) Impossible to fumigate. Try prebaiting-poisoning as palliative . 14
4. (*a*) Premises part of large block 5
   (*b*) Premises isolated 7
5. (*a*) Infestation extensive 6
   (*b*) Infestation circumscribed 7
6. Determine by inspection best unit(s) to treat 7
7. (*a*) Food can be removed or locked up and cover 'shaken up' . . 8
   (*b*) Food must remain 14
8. (*a*) Medium to small infestation 9
   (*b*) Large infestation 11
9. (*a*) No objection to traps (because of, for example, dogs, children) . 10
   (*b*) Traps undesirable 11
10. *Trap with break-back traps* (c. *6 to a small room*) *baited with a pinch of rolled oats or flour for 3 nights, then take up traps. Repeat trapping only after interval of 14–21 days.*
11. (*a*) Environment 'dry'—low humidity, no free water or wet food . 12
    (*b*) Environment 'wet' 13
12. *Direct poisoning with 5% zinc phosphide in moist sausage-rusk with* c. *twenty 3-g. baits per small room. Recover corpses and residual poison bait.*
13. *Direct poisoning with 5% zinc phosphide in rolled oats with* c. *twenty 1-g. baits per small room. Recover corpses and residual poison bait.*
14. (*a*) Time and expense relatively unimportant 15
    (*b*) Time and expense important 16
15. Do choice test with plain baits, placing 1–6 points with 20 g. each of moist sausage-rusk, rolled oats, and flour. Observe preference in 1–2 days 17
16. (*a*) Environment dry. Use moist sausage-rusk and proceed to prebaiting 17
    (*b*) Environment wet. Use rolled oats and proceed to prebaiting . 17
17. Place small piles (1–5 g. or enough to cover a halfpenny) everywhere where there are mouse traces, especially near holes, along skirtings, in cupboards, and on shelves (12–20 baits per small room). Examine next day and determine whether
    (*a*) Mice have eaten from these at random 18
    (*b*) Mice have eaten from some places more than from others . . 19
18. Replace eaten baits with increased number until the maximum consumption is reached (or for 3 days) 20

19. Gradually (over 2–3 days) concentrate and increase number of bait piles at places where activity is greatest. This should reveal the pattern and source(s) of the infestation 20
20. (*a*) Unavoidable danger to animals from poison bait 21
(*b*) No danger to animals, or, if present, they can be confined during the poisoning night 22
21. Poison with water extract of red squill. If rolled oats is being used, this must be moistened with a quarter of its weight of water . . . 25
22. (*a*) Corpse smell to be avoided 23
(*b*) Corpse smell not important (only troublesome anyway with many mice). 24
23. Poison with 10% arsenious oxide 25
24. Poison with 5% zinc phosphide 25
25. Put down freshly mixed poison bait in evening (or when premises become quiet), using about half the total of the prebait peak. This must be placed in exactly the same positions as the prebait 26
26. (*a*) No time for proper evaluation of results 27
(*b*) Time for follow-up treatment 28
27. *Remove carefully all poison residues and collect corpses.*
28. (*a*) Arsenious oxide used 29
(*b*) Zinc phosphide or squill used 30
29. Clear up poison bait residues and corpses. Place plain bait again as before, replenish at intervals for about a week before judging success of clearance 31
30. Clear up poison bait residues (not so important with squill) and corpses. Place bait again as before for 2–3 days before judging success of clearance 31
31. (*a*) Clearance complete or nearly so 32
(*b*) Residue of mice left 33
32. *Seal up all entrances with tin-plate or, where this is too unsightly, with plaster. Treat reinvasion as a new infestation.*
33. *If mice are still left, continue plain baiting and poison again at intervals of 10–20 days changing the poison used each time, or including a masking substance with the poison bait.*

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